



US006553568B1

(12) **United States Patent**  
Fijolek et al.(10) Patent No.: **US 6,553,568 B1**(45) Date of Patent: **Apr. 22, 2003**(54) **METHODS AND SYSTEMS FOR SERVICE  
LEVEL AGREEMENT ENFORCEMENT ON A  
DATA-OVER CABLE SYSTEM**(75) Inventors: **John G. Fijolek**, Naperville, IL (US);  
**Phillip T. Robinson**, Lake Barrington,  
IL (US); **Irene M. Gilbert**, Palatine, IL  
(US); **Daniel M. Budinger**, Arlington  
Heights, IL (US); **Narrij Jain**, San Jose,  
CA (US)(73) Assignee: **3Com Corporation**, Santa Clara, CA  
(US)(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 0 days.(21) Appl. No.: **09/407,337**(22) Filed: **Sep. 29, 1999**(51) Int. Cl.<sup>7</sup> ..... **H04N 7/173; G06F 15/16**(52) U.S. Cl. .... **725/111; 725/100; 725/86;**  
709/218(58) Field of Search ..... 725/86, 95, 100,  
725/111; 709/218(56) **References Cited****U.S. PATENT DOCUMENTS**

4,881,263 A	11/1989	Herbison et al.	380/21
4,996,685 A	2/1991	Farese et al.	370/58.1
5,014,234 A	5/1991	Edwards, Jr.	364/900
5,138,712 A	8/1992	Corbin	
5,301,273 A	4/1994	Konishi	395/200
5,347,304 A	9/1994	Moura et al.	348/12
5,430,727 A	7/1995	Callon	370/85.13
5,442,749 A	8/1995	Northcutt et al.	
5,488,412 A	1/1996	Majeti et al.	348/10
5,489,897 A	2/1996	Inoue	340/870.39
5,583,931 A	12/1996	Schneider et al.	379/399
5,586,121 A	12/1996	Moura et al.	370/404
5,600,717 A	2/1997	Schneider et al.	379/399
5,606,606 A	2/1997	Schneider et al.	379/399
5,608,446 A	3/1997	Carr et al.	348/6

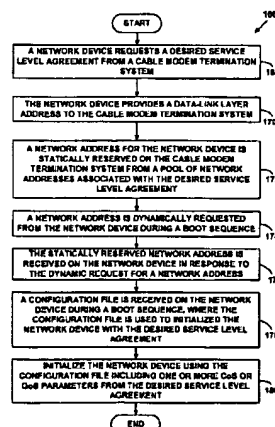
(List continued on next page.)

**OTHER PUBLICATIONS**"Cable Modem to Customer Premise Equipment Interface  
Specification (Interim) SP-CMCI-102-980317", Multime-  
dia Cable Network Systems (MCNS) Holdings, L.P., Cable  
Television Laboratories, Inc., 1998, pp. ii to 40.

(List continued on next page.)

*Primary Examiner*—Krisna Lim(74) *Attorney, Agent, or Firm*—McDonnell Boehnen  
Hulbert & Berghoff(57) **ABSTRACT**

Methods and system for service level agreement enforce-  
ment on a data-over-cable system. One or more service level  
agreements are created including one or more class-of-  
service or quality-of-service parameters. A pool of Internet  
Protocol addresses is allocated for the one or more service  
level agreements. Configuration files including service level  
agreement parameters are used to initialize cable modems or  
customer premise equipment. When a cable modem or  
customer premise equipment requests use of a service level  
agreement, an Internet Protocol address from the pool of  
Internet Addresses associated with a desired service level  
agreement is assigned. The service level agreements are  
enforced using the Internet Protocol address from a cable  
modem termination system including an integral switch  
cable access router and a bandwidth manager. The cable  
modem termination system with integral components are  
duplicated to provide a "hot back" up in case of failure and  
increase reliability for using service level agreements. The  
cable access router enforces maximum rate limits for service  
level agreements. The switch switches data streams from  
external networks from the data-over-cable system. The  
bandwidth manager provides class-of-service or quality-of-  
service services with policy management and detects net-  
work trends, measures network response time and generates  
reports. The bandwidth manager also monitors, regulates  
and shapes traffic based on service level agreement requests  
at a data-link layer level. The methods and system allow  
service level agreements to be used on a data-over-cable  
system without adversely affecting performance or through-  
put on the data-over-cable system. The methods and system  
may also help provide service level agreements in a data-  
over-cable system in a more reliable manner.

**6 Claims, 10 Drawing Sheets**

## U.S. PATENT DOCUMENTS

5,610,910 A	3/1997	Focsaneanu et al. ....	370/351	6,216,171 B1	4/2001	Isono et al. ....	709/250
5,623,542 A	4/1997	Schneider et al. ....	379/399	6,223,222 B1	4/2001	Fijolek et al. ....	709/227
5,623,601 A	4/1997	Vu		6,240,464 B1	5/2001	Fijolek et al. ....	709/250
5,636,211 A	6/1997	Newlin	370/465	6,260,072 B1	7/2001	Rodriguez-Moral	709/241
5,675,732 A	10/1997	Majeti et al.		6,269,099 B1	7/2001	Borella et al. ....	370/389
5,675,742 A	10/1997	Jain et al. ....	395/200	6,272,150 B1	8/2001	Hrastar	370/486
5,678,041 A	10/1997	Baker et al. ....	395/609	6,275,853 B1	8/2001	Beser et al. ....	709/223
5,708,654 A	1/1998	Arndt et al. ....	370/242	6,295,554 B1	9/2001	Karadogan	709/219
5,710,885 A	1/1998	Bondi		6,301,223 B1	10/2001	Hrastar et al. ....	370/227
5,724,510 A	3/1998	Arndt et al.		6,301,618 B1	10/2001	Sitaraman et al. ....	709/227
5,761,602 A	6/1998	Wagner et al. ....	455/3.1	6,308,328 B1	10/2001	Bowcutt et al. ....	725/111
5,778,181 A	7/1998	Hidary et al.		6,331,987 B1	12/2001	Beser	370/486
5,790,198 A	8/1998	Roop et al. ....	348/460	6,332,163 B1	12/2001	Bowman-Amuah	709/231
5,790,548 A	8/1998	Sistanizadeh et al. ....	370/401	6,337,858 B1	1/2002	Petty et al. ....	709/356
5,790,677 A	8/1998	Fox et al. ....	380/24	6,351,773 B1	2/2002	Fijolek et al. ....	709/228
5,790,770 A	8/1998	McClure et al.		6,370,147 B1	4/2002	Beser	370/401
5,790,806 A	8/1998	Koperda		OTHER PUBLICATIONS			
5,793,747 A	8/1998	Kline	370/230	"Operations Support System Interface Specification Base-			
5,799,086 A	8/1998	Sudia	380/23	line Privacy Interface MIB (Interim Specification) SP-OS-			
5,805,804 A	9/1998	Laursen et al.		SI-BPI-101-980331", MCNS Holdings, L.P., 1997 and			
5,812,819 A	9/1998	Rodwin et al. ....	395/500	1998, pp. ii to 33.			
5,818,845 A	10/1998	Moura et al. ....	370/449	"Cable Modem Termination System-Network Side Inter-			
5,819,042 A	10/1998	Hansen		face Specification (Interim Specification) SP-C-			
5,828,655 A	10/1998	Moura et al. ....	370/236	MTS-NSI101-960702", MCNS Holdings, L.P., 1996, pp. ii			
5,828,666 A	10/1998	Focsaneanu et al. ....	370/389	to 13.			
5,835,727 A	11/1998	Wong et al.		"Removable Security Module Interface Specification			
5,848,233 A	12/1998	Radia et al. ....	395/187.01	(Interim Specification) SP-RSM1-101-980204", MCNS			
5,852,721 A	12/1998	Dillon et al.		Holdings, L.P., Cable Television Laboratories, Inc., 1997,			
5,854,901 A	12/1998	Cole et al. ....	709/245	pp. ii to 47.			
5,859,852 A	1/1999	Moura et al. ....	370/449	"Baseline Privacy Interface Specification (Interim) SP-B-			
5,864,679 A	1/1999	Kanai et al. ....	709/238	PI-101-970922", MCNS Holdings, L.P., 1997, pp. ii to 65.			
5,870,134 A	2/1999	Laubach et al. ....	348/12	"Operations Support System Interface Specification			
5,872,523 A	2/1999	Dellaverson et al. ..	340/825.52	(Interim) SP-OSS101-970403", MCNS Holdings, L.P.,			
5,884,024 A	3/1999	Lim et al.		1997, pp. 1 to 30.			
5,892,754 A	4/1999	Kompella et al. ....	370/236	"Radio Frequency Interface Specification (Interim Specifi-			
5,894,479 A	4/1999	Mohammed	370/401	cation) SP-RFI-102-971008", MCNS Holdings, L.P., 1997,			
5,909,549 A	6/1999	Compliment et al. ....	709/223	pp. ii to 186.			
5,915,119 A	6/1999	Cone		"Cable Modem Telephony Return Interface Specification			
5,922,049 A	7/1999	Radia et al. ....	709/220	(Interim) SP-CMTR1-101-970804", MCNS Holdings, L.P.,			
5,923,659 A	7/1999	Curry et al. ....	370/401	Cable Television Laboratories, Inc., 1997, pp. ii to 73.			
5,926,458 A	7/1999	Yin	370/230	"Security System Specification (Interim Specification)			
5,958,007 A	9/1999	Lee et al. ....	709/219	SP-SSI-101-970506", MCNS Holdings, L.P., 1997, pp. ii to			
5,974,453 A	10/1999	Anderson et al. ....	709/220	103.			
5,982,748 A	11/1999	Yin et al. ....	370/232	"Internet Engineering Task Force", Request for Comments			
5,987,524 A	11/1999	Yoshida et al. ....	709/245	2131, Dynamic Host Configuration Protocol (DHCP), Mar.			
5,991,292 A	11/1999	Focsaneanu et al. ....	370/352	1997, pp. 1 to 42.			
5,991,306 A	11/1999	Burns et al. ....	370/429	S. Adiraju, J. Fijolek, IPCDN Telephony Return MIP, Inter-			
5,996,076 A	11/1999	Rowney et al. ....	713/201	net Engineering Task Force, Internet Draft,			
5,999,536 A	12/1999	Kawafuji et al. ....	370/401	"draft-ietf-ipcdn-tri-mib-00.1.txt", Mar. 1998, pp. 1 to			
6,009,103 A	12/1999	Woundy	370/401	26.			
6,012,088 A	1/2000	Li et al. ....	709/219	"Radio Frequency Interface (Interim Specification)			
6,013,107 A	1/2000	Blackshear et al. ....	703/229	SP-RFI-104-980724", MCNS Holdings, L.P., 1997, pp. ii to			
6,018,767 A	1/2000	Fijolek et al. ....	709/218	196.			
6,031,841 A	2/2000	Woundy	370/410	"Radio Frequency Interface Specification (Interim Specifi-			
6,046,979 A	4/2000	Bauman	370/229	cation) SP-RFI-105-991105", MCNS Holdings, L.P., 1999,			
6,049,825 A	4/2000	Yamamoto	709/221	pp. ii to 202.			
6,049,826 A	4/2000	Beser	709/222	"Radio Frequency Interface Specification (Interim Specifi-			
6,058,421 A	5/2000	Fijolek et al. ....	709/225	cation) SP-RFIV1.1-106-001215", MCNS Holdings, L.P.,			
6,061,349 A	5/2000	Coile et al. ....	370/389	2000, pp. ii to 432.			
6,070,187 A	5/2000	Subramaniam et al. ....	709/220	Kyees, P.J. et al., <i>ADSL: A New Twisted-Pair Access to the</i>			
6,070,246 A	5/2000	Beser	713/201	<i>Information Highway</i> , IEEE Communications Magazine,			
6,104,700 A	8/2000	Haddock et al. ....	370/235	vol. 33, Issue 4, Apr. 1995, pp. 52-60.			
6,112,258 A	8/2000	Miller et al. ....	710/19	Huang, Yin-Hwa et al., <i>Design of an MPEG-Based Set-Top</i>			
6,122,254 A	9/2000	Aydemir et al. ....	370/235	<i>Box for Video on Demand Services</i> , Acoustics, Speech, and			
6,128,298 A	10/2000	Wootton et al. ....	370/392	Signal Processing, 1995, ICASSP-95., 1995 International			
6,130,879 A	10/2000	Liu	370/230	Conference, vol. 4, ISBN: 0-7803-2431-5, May 9-12,			
6,137,792 A	10/2000	Jonas et al. ....	370/354	1995, pp. 2655-2658.			
6,137,793 A	10/2000	Gorman et al. ....	370/360				
6,148,410 A	11/2000	Baskey et al. ....	714/4				
6,178,455 B1	1/2001	Schutte et al. ....	709/228				
6,189,102 B1	2/2001	Beser	713/201				
6,208,656 B1	3/2001	Hrastar et al. ....	370/401				
6,212,563 B1	4/2001	Beser	709/227				

FIG. 1

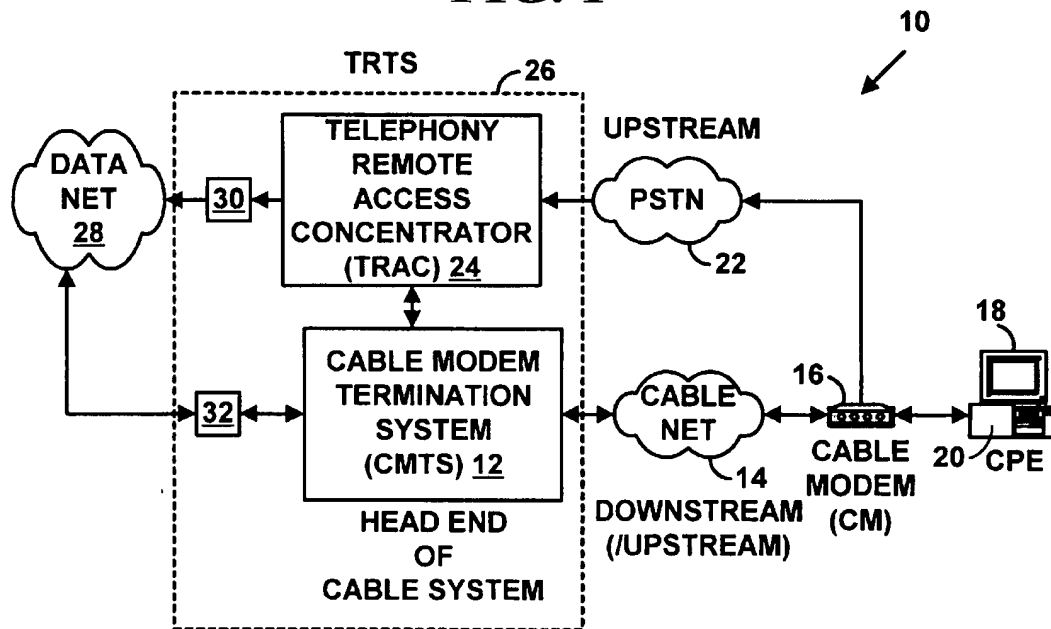
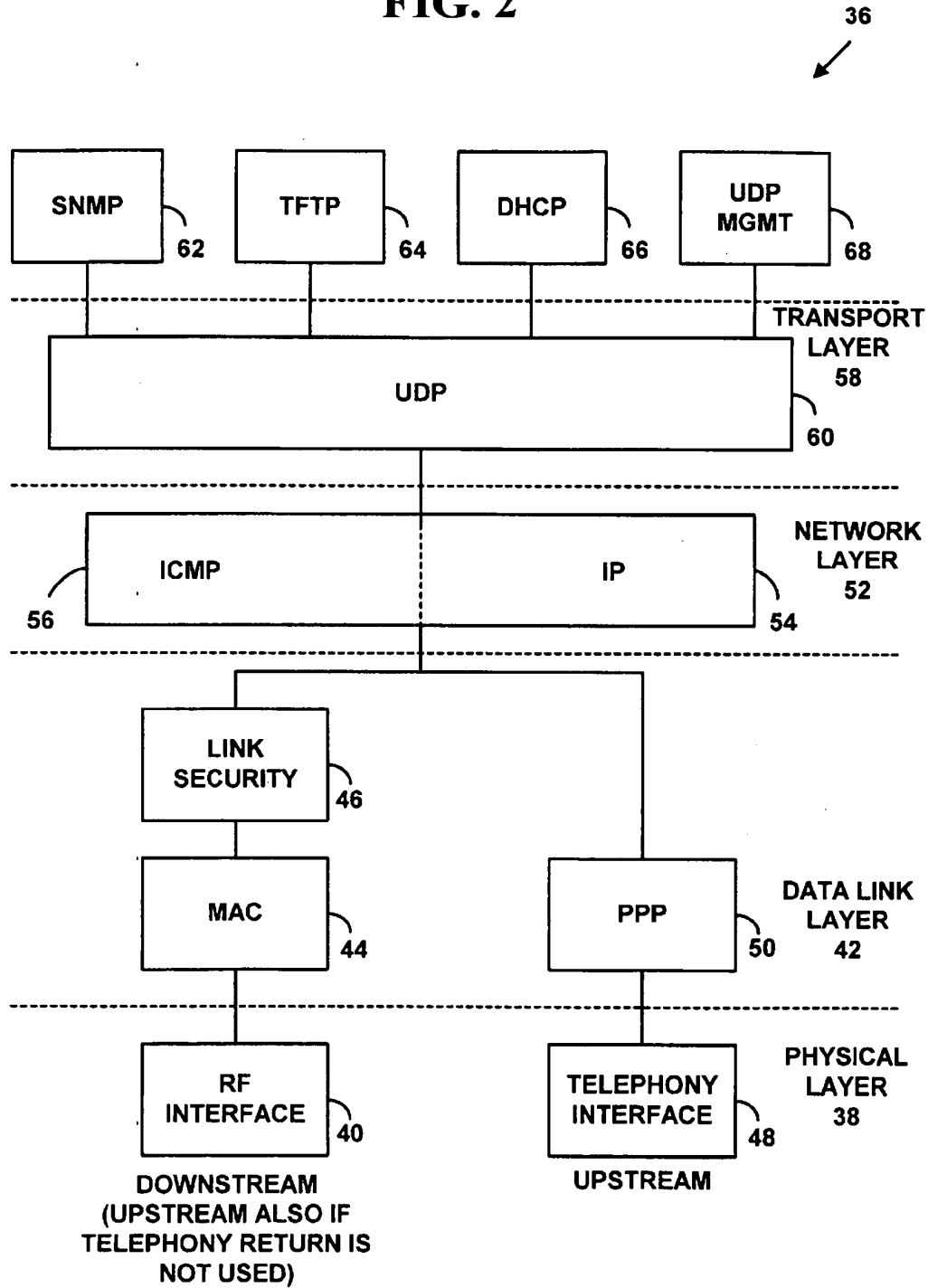
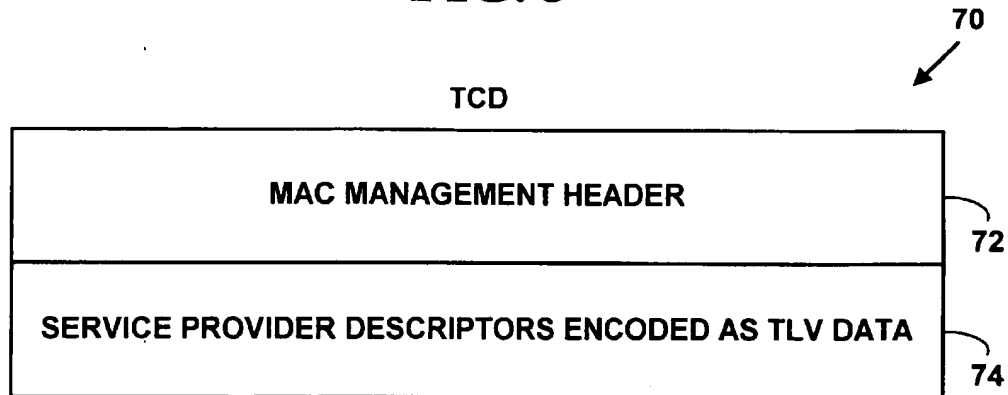
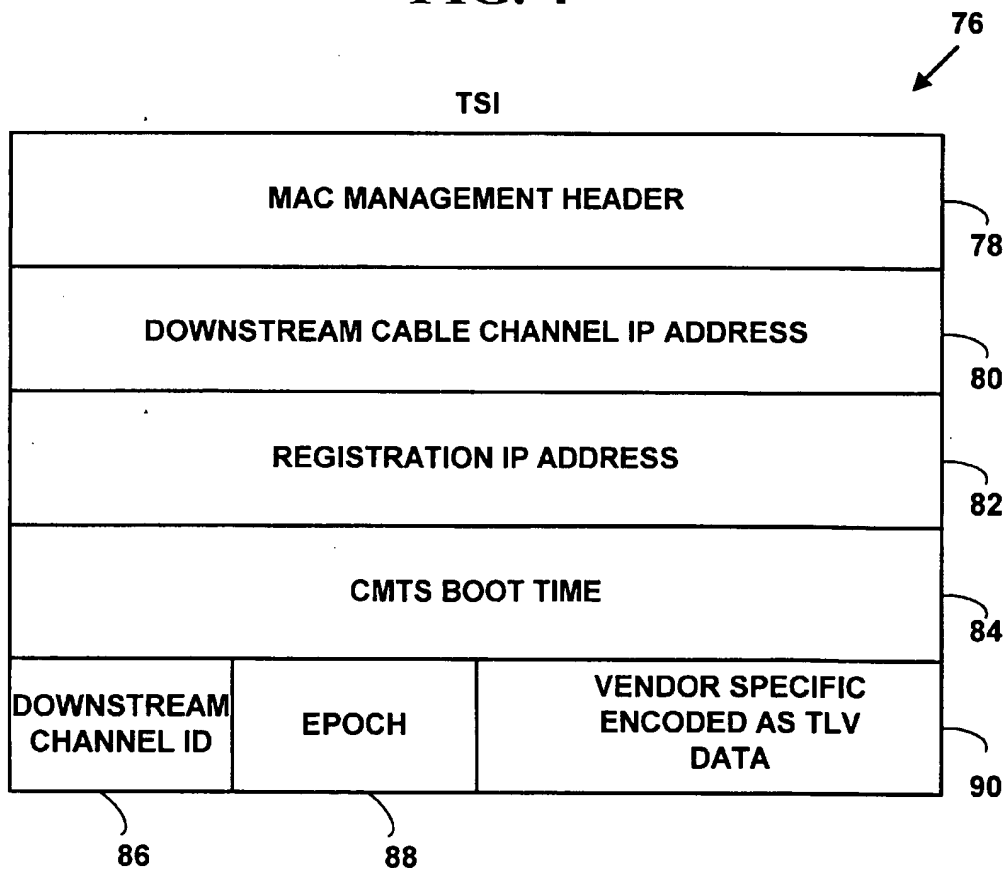


FIG. 2



**FIG. 3****FIG. 4**

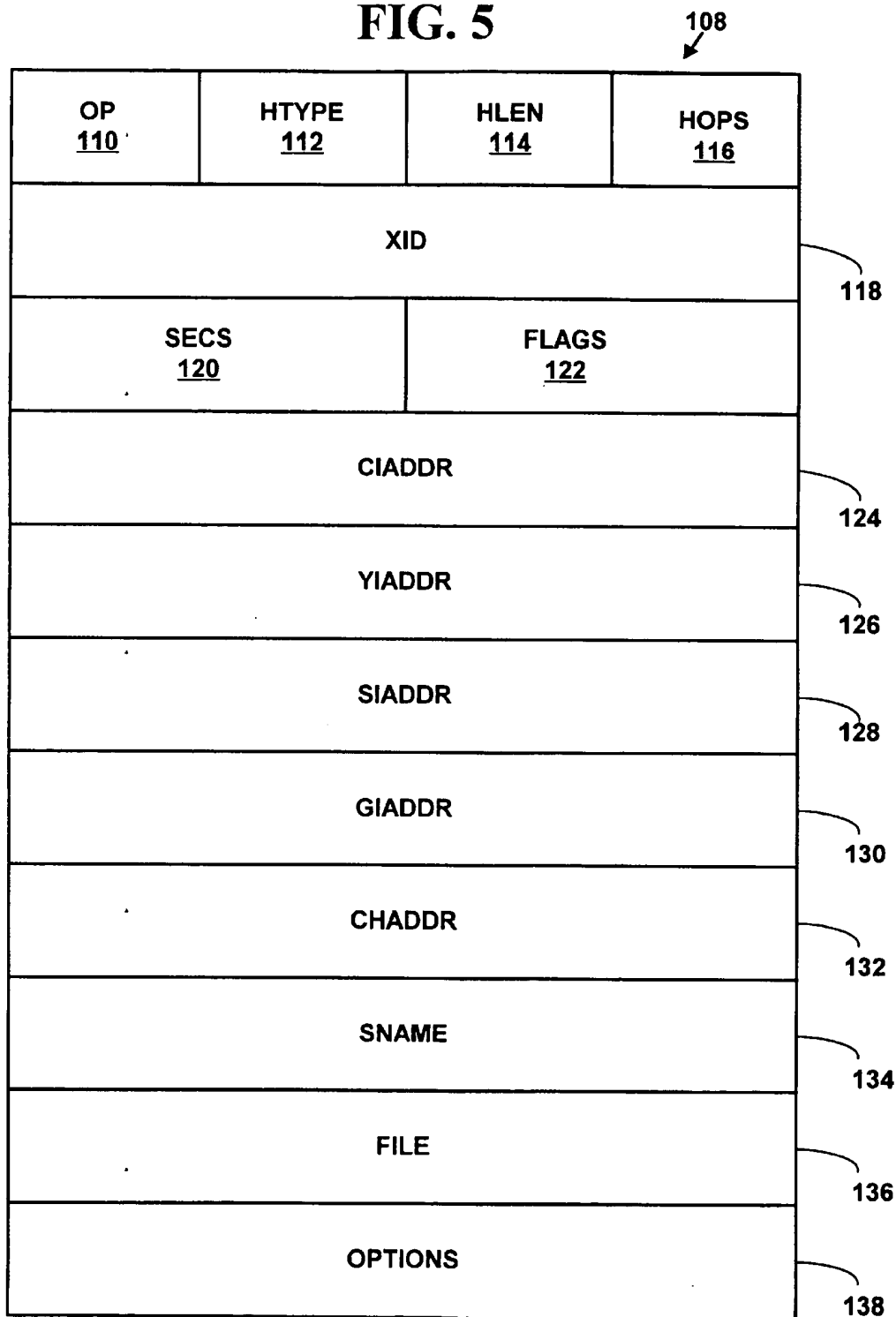
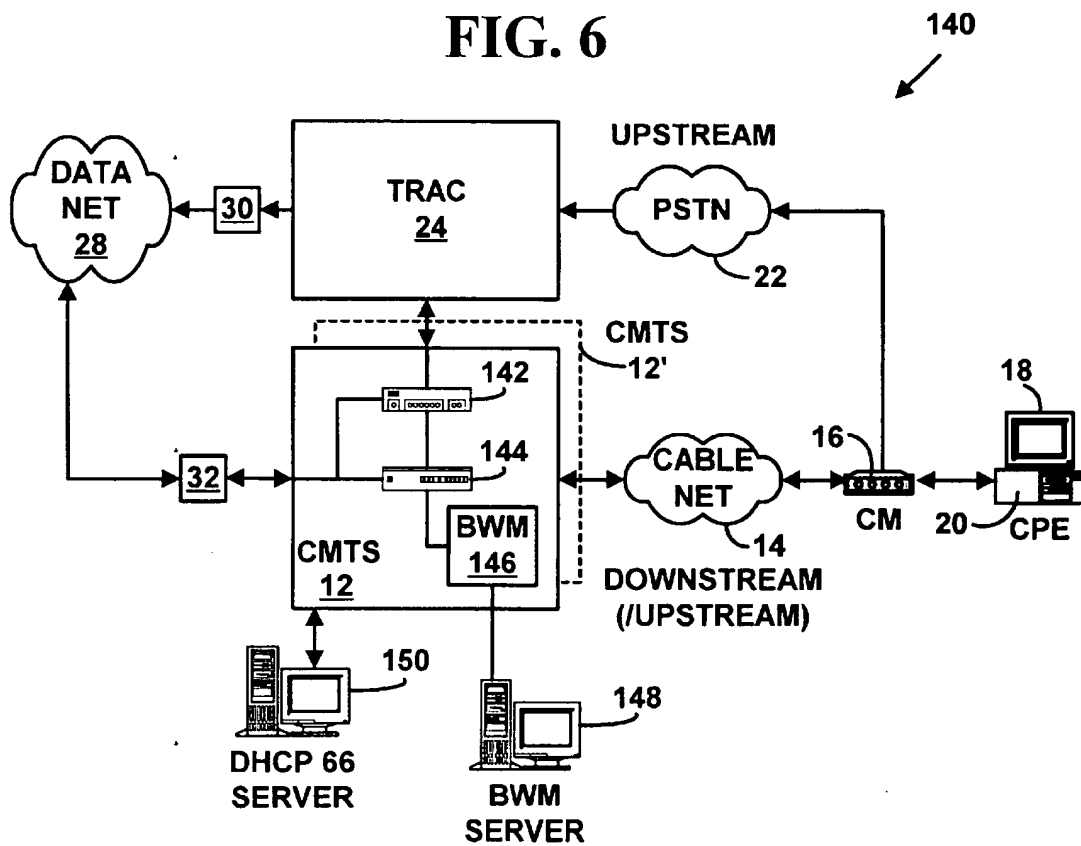
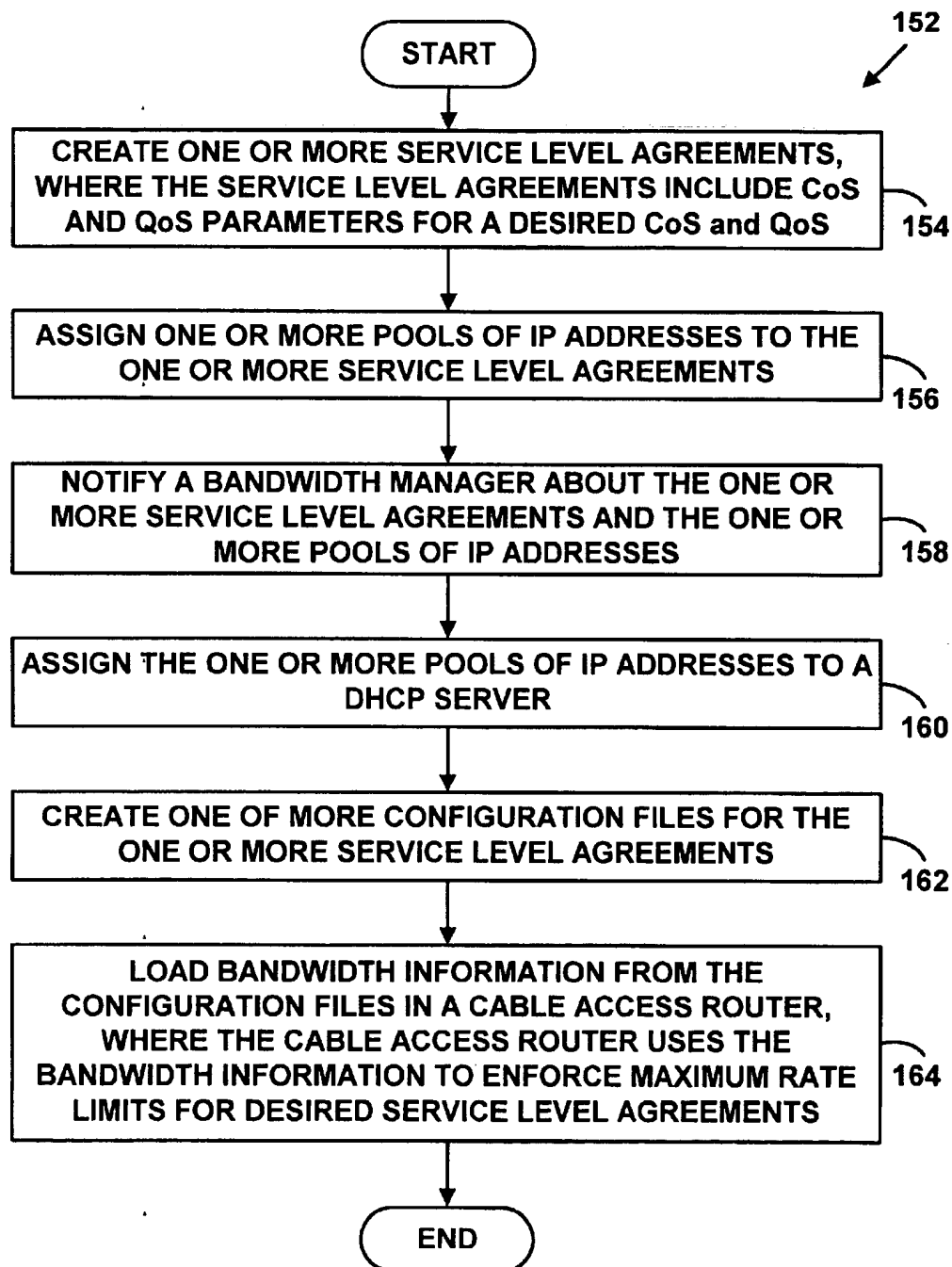
**FIG. 5**

FIG. 6



**FIG. 7**



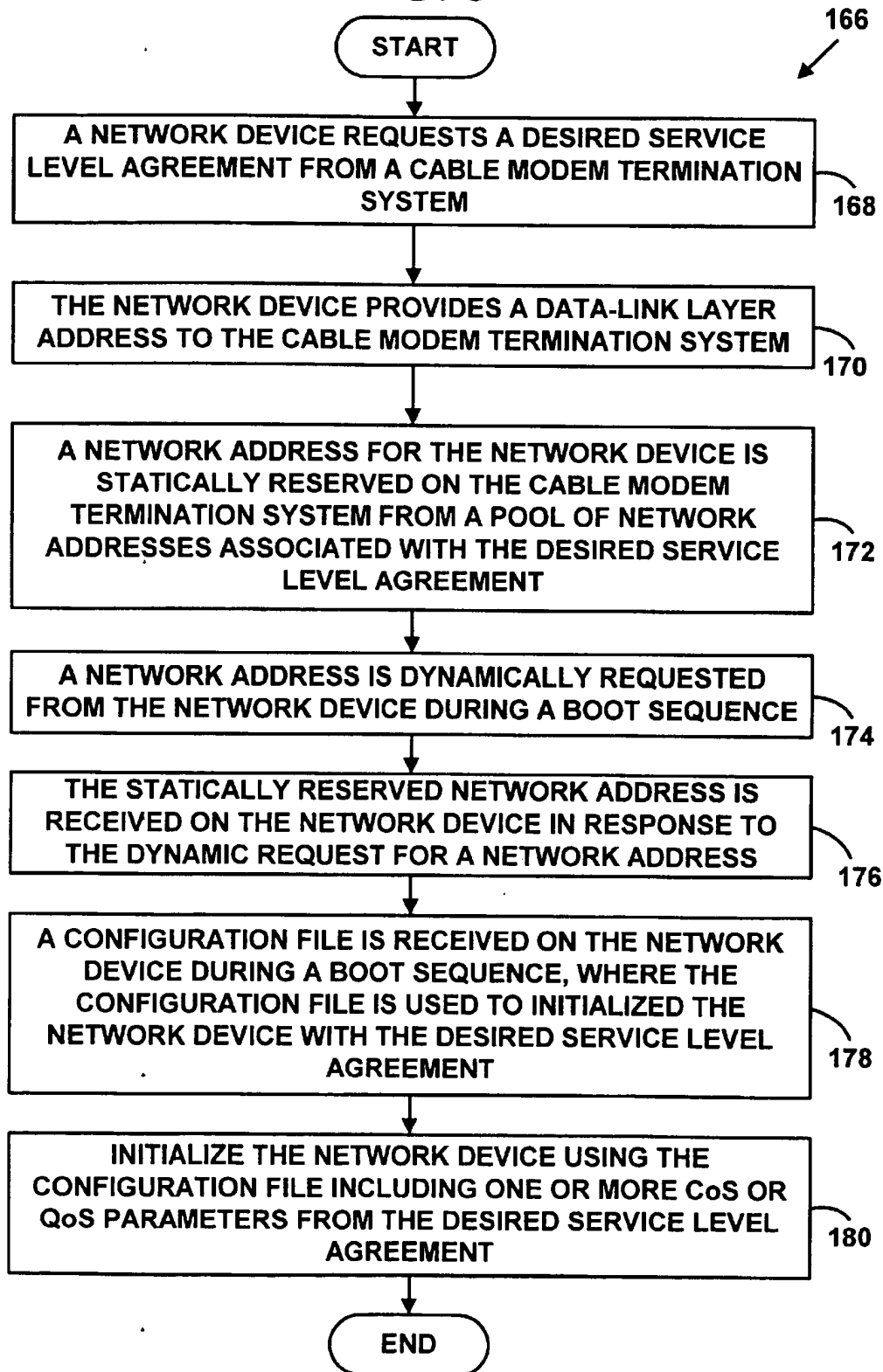
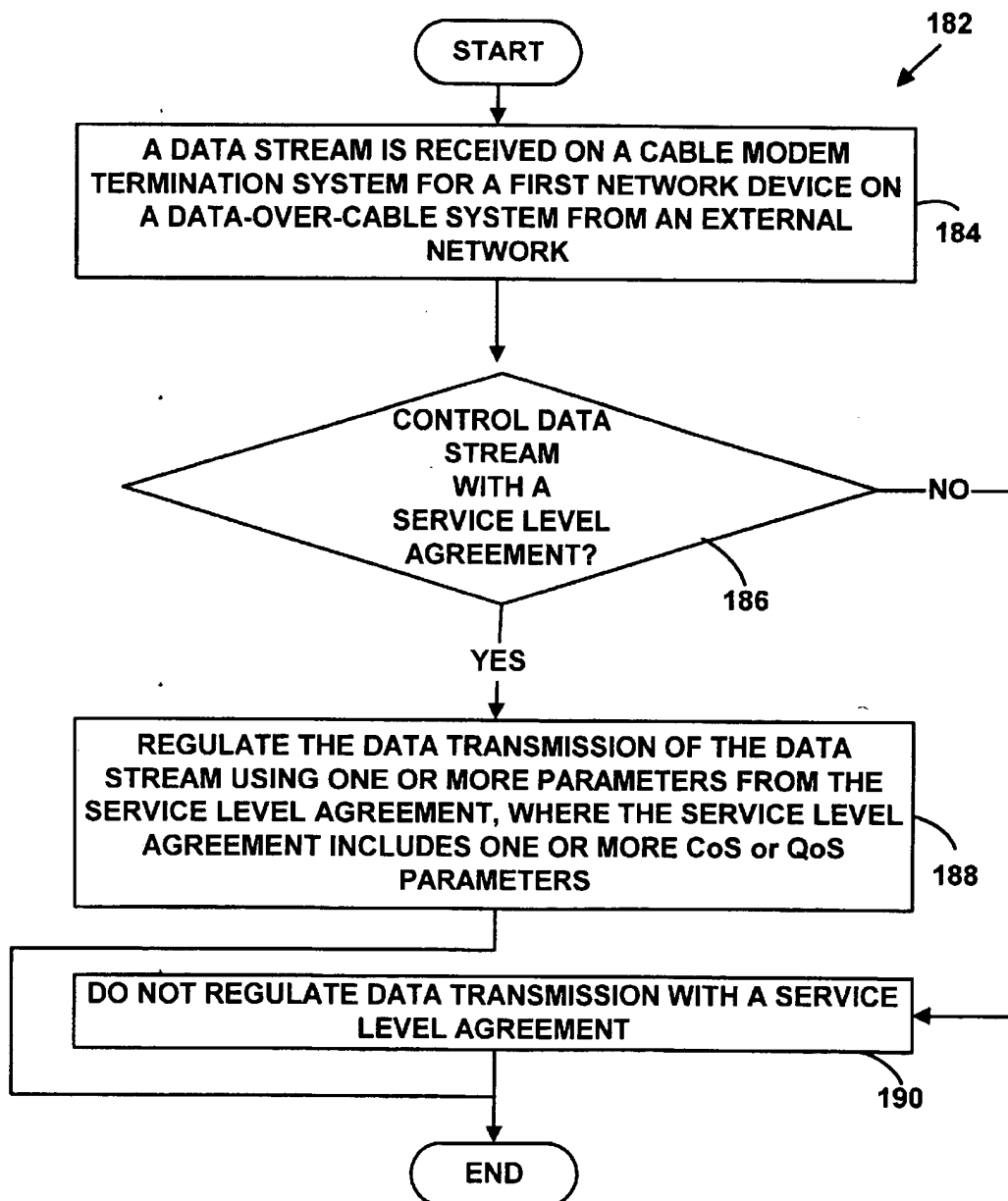
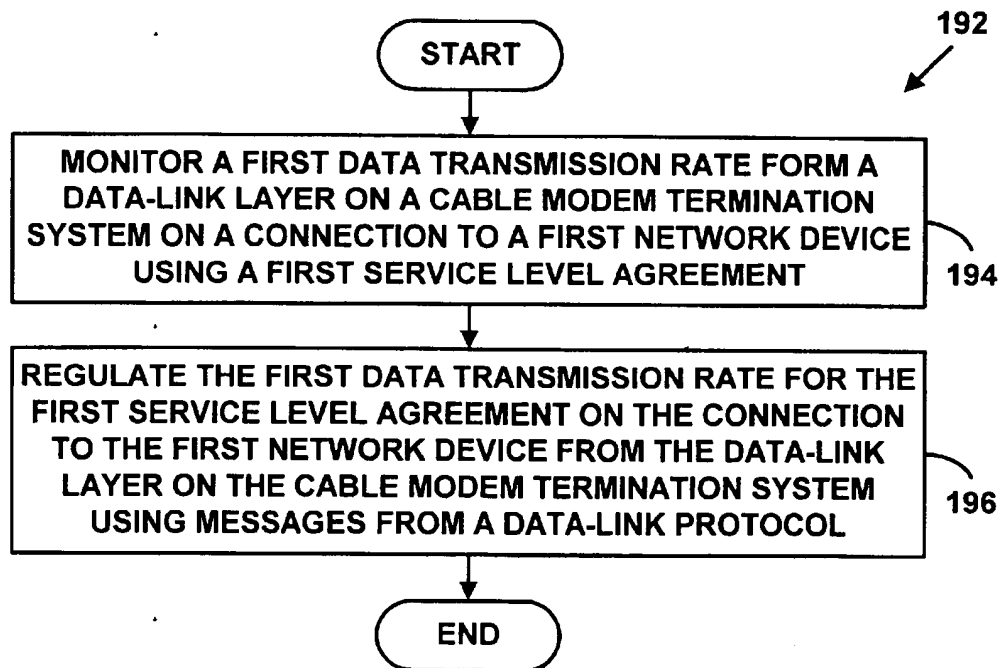
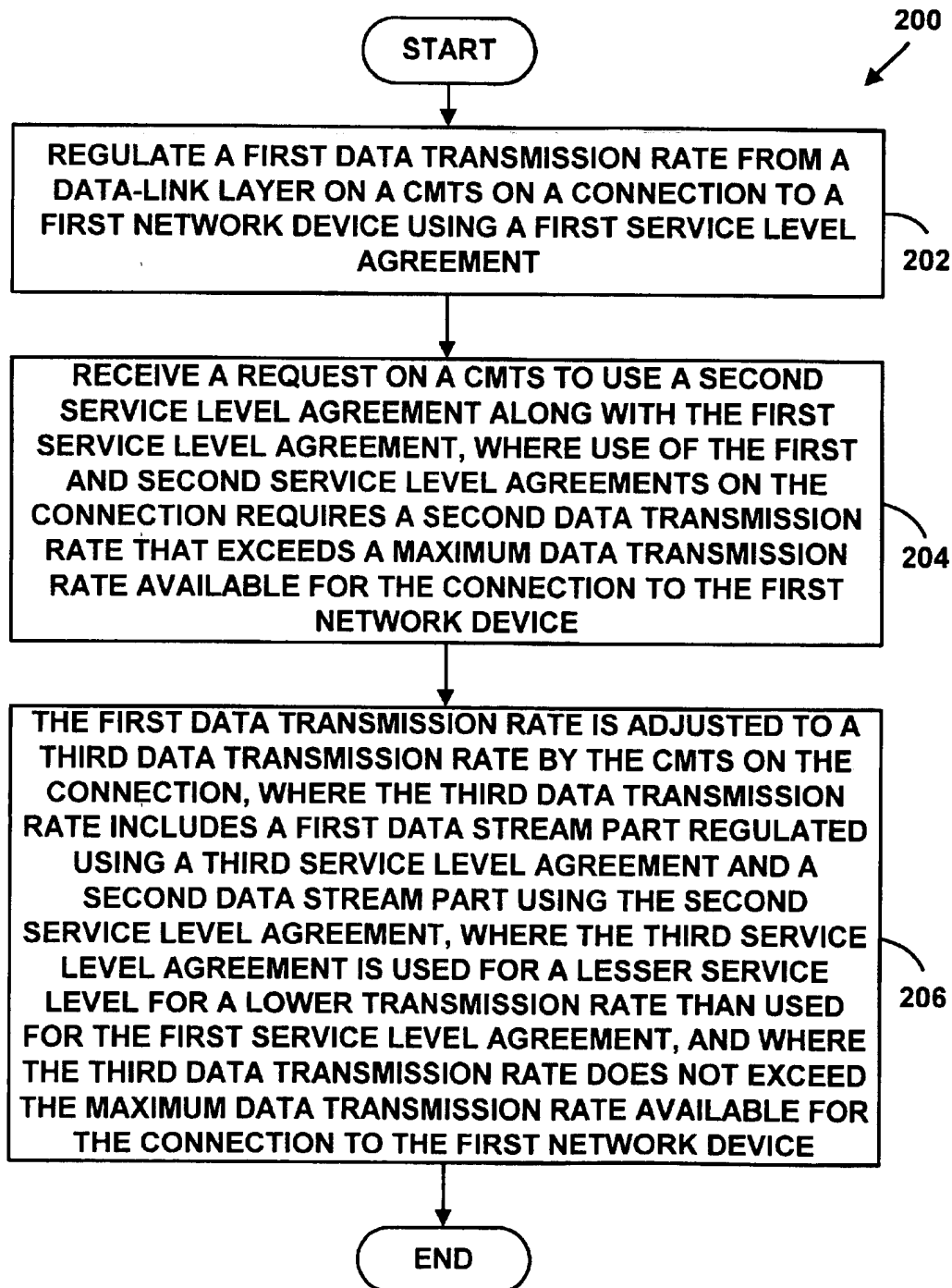
**FIG. 8**

FIG. 9



**FIG. 10**

**FIG. 11**

# METHODS AND SYSTEMS FOR SERVICE LEVEL AGREEMENT ENFORCEMENT ON A DATA-OVER CABLE SYSTEM

## FIELD OF INVENTION

The present invention relates to communications in computer networks. More specifically, it relates to data rate enforcement, such as class-of-service or quality-of-service service enforcement for service level agreements on a cable television network.

## BACKGROUND OF THE INVENTION

Cable television networks such as those provided by Comcast Cable Communications, Inc., of Philadelphia, Pa., Cox Communications of Atlanta, Ga., Tele-Communications, Inc., of Englewood Colo., Time-Warner Cable, of Marietta Ga., Continental Cablevision, Inc., of Boston Mass., and others provide cable television services to a large number of subscribers over a large geographical area. The cable television networks typically are interconnected by cables such as coaxial cables or a Hybrid Fiber/Coaxial ("HFC") cable system which have data rates of about 10 Mega-bits-per-second ("Mbps") to about 30+ Mbps.

The Internet, a world-wide-network of interconnected computers, provides multi-media content including audio, video, graphics and text that typically requires a large bandwidth for downloading and viewing. Most Internet Service Providers ("ISPs") allow customers to connect to the Internet via a serial telephone line from a Public Switched Telephone Network ("PSTN") at data rates including 14,400 bps, 28,800 bps, 33,600 bps, 56,000 bps and others that are much slower than the about 10 Mbps to about 30+ Mbps available on a coaxial cable or HFC cable system on a cable television network.

With the explosive growth of the Internet, many customers have desired to use the larger bandwidth of a cable television network to connect to the Internet and other computer networks. Cable modems, such as those provided by 3Com Corporation, of Santa Clara, Calif., Motorola Corporation, of Arlington Heights, Ill., Hewlett-Packard Co., of Palo Alto, Calif., Bay Networks, of Santa Clara, Calif., Scientific-Atlanta, of Norcross, Ga., General Instruments, of Horsham, Pa., and others offer customers higher-speed connectivity to the Internet, an intranet, Local Area Networks ("LANs") and other computer networks via cable television networks. These cable modems currently support a data connection to the Internet and other computer networks via a cable television network with a data rate of up to about 30+ Mbps, which is a much larger data rate than can be supported by a modem used over a serial telephone line.

However, many cable television networks provide only uni-directional cable systems, supporting only a "downstream" cable data path. A downstream data path is the flow of data from a cable system "headend" to a customer. A cable system headend is a central location in the cable television network that is responsible for sending cable signals in the downstream direction. A return data path via a telephone network (i.e., a "telephony return"), such as a public switched telephone network provided by AT&T, GTE, Sprint, MCI and others, is typically used for an "upstream" data path. An upstream data path is the flow of data from the customer back to the cable system headend. A cable television system with an upstream connection to a telephony network is called a "data-over-cable system with telephony return."

An exemplary data-over-cable system with telephony return includes customer premise equipment (e.g., a customer computer), a cable modem, a cable modem termination system, a cable television network, a public switched telephone network, a telephony remote access concentrator and a data network (e.g., the Internet). The cable modem termination system and the telephony remote access concentrator together are called a "telephony return termination system."

The cable modem termination system receives data packets from the data network and transmits them downstream via the cable television network to a cable modem attached to the customer premise equipment. The customer premise equipment sends response data packets to the cable modem, which sends response data packets upstream via public switched telephone network to the telephony remote access concentrator, which sends the response data packets back to the appropriate host on the data network.

In a two-way cable system without telephony return, the customer premise equipment sends response data packets to the cable modem, which sends the data packets upstream via the cable television network to the cable modem termination system. The cable modem termination system sends the data packets to appropriate hosts on the data network. The cable modem termination system sends the response data packets back to the appropriate cable modem.

As a cable modem is initialized in a data-over-cable system, it registers with a cable modem termination system to allow the cable modem to receive data over a cable television connection and from a data network (e.g., the Internet or an Intranet). The cable modem forwards configuration information it receives in a configuration file during initialization to the cable modem termination system as part of a registration request message. A cable modem also helps initialize and register any attached customer premise equipment with the cable modem termination system.

A cable modem termination system in a data-over-cable system typically manages connections to tens of thousands of cable modems. Most of the cable modems are attached to host customer premise equipment such as a customer computer. To send and receive data to and from a computer network like the Internet or an intranet, a cable modem and customer premise equipment and other network devices have a network address dynamically assigned on the data-over-cable system.

Many data-over-cable systems use a Dynamic Host Configuration Protocol ("DHCP") as a standard messaging protocol to dynamically allocate network addresses such as Internet Protocol ("IP") addresses. As is known in the art, the Dynamic Host Configuration Protocol is a protocol for passing configuration information to network devices on a network. The Internet Protocol is an addressing protocol designed to route traffic within a network or between networks.

Initialization information forwarded to a cable modem termination system from a cable modem may include Class-of-Service ("CoS") or Quality-of-Service ("QoS") requests. As is known in the art, class-of-service provides a reliable (i.e., error free, in sequence, with no loss of duplication) transport facility independent of the quality-of-service. Class-of-service parameters include maximum downstream data rates, maximum upstream data rates, upstream channel priority, guaranteed minimum data rates, guaranteed maximum data rate and other parameters. Quality-of-service collectively specifies the performance of a network service

that a device expects on a network. Quality-of-service parameters include transit delay expected to deliver data to a specific destination, the level of protection from unauthorized monitoring or modification of data, cost for delivery of data, expected residual error probability, the relative priority 5 associated with the data and other parameters.

A cable modem termination system is typically responsible for providing class-of-service and quality-of-service connections to a cable modem in a data-over-cable system. However, there are several problems associated with using a cable modem termination system to provide class-of-service and quality-of-service connections to a cable modem. One problem is that the cable modem termination system is responsible for handling and balancing class-of-service and quality-of-service requests for tens of thousands 10 of cable modems. The handling and balancing class-of-service and quality-of-service includes allocating bandwidth for guaranteed transmission rates requested by the cable modems. The handling and balancing requires significant computational and computer resources on the cable modem termination system. The cable modem termination system uses complex software that is not easily adaptable to new or additional class-of-service or quality-of-service parameters. In addition, multiple cable modem termination systems in a data-over-cable systems typically do not handle or balance 15 class-of-service or quality-of-service parameters in a standard way.

Another problem is that a cable modem termination system may have to bridge class-of-service or quality-of-service across networks with different underlying technologies (e.g., between a public switched telephone network and a cable television network or between the Internet or an intranet and a cable television network) without affecting system performance or throughput.

Another problem is that providing class-of-service and quality-of-service using a single networking device such as a cable modem termination system makes a network including such a networking device vulnerable to failures should the networking device fail. This could lead to user frustration for users who are willing to pay additional fees for desired class-of-service or quality-of-service features and not receive such features on a consistent basis.

Another problem is that current networking devices such as a cable modem termination system that provide class-of-service and quality-of-service typically do not detect network traffic trends, measure network response time or generate class-of-service and quality-of-service reports.

Yet another problem is that current networking devices such as a cable modem termination system that provide 20 class-of-service and quality-of-service typically do not provide enforcement of service level agreements ("SLAs"). As is known in the art, service level agreements are used to determine what policies, programs and/or data transmission rates will be offered to customers.

Thus, it is desirable to provide a standard, efficient and reliable way to provide class-of-service or quality-of-service and service level agreements to customers in a data-over-cable system. The class-of-service or quality-of-service and service level agreements should also be provided across 25 networks without affecting system performance or throughput.

#### SUMMARY OF THE INVENTION

In accordance with preferred embodiments of the present invention, some of the problems associated with providing class-of-service or quality-of-service on a data-over-cable

system are overcome. One aspect of the invention includes a method for providing service level agreements. One or more service level agreements are created along with one or more pools of network addresses. Network addresses are assigned from the pools when a network device requests a desired service level agreement. One or more configuration files including class-of-service or quality-of-service parameters are also created to initialize a network device for a desired service level agreement.

Another aspect of the invention includes a method for requesting a service level agreement. A network device requests a service level agreement. The network device is assigned a network address from a pool of network addresses associated with the service level agreement. The network device also receives a configuration file including service level agreement parameters. The service level agreement includes one or more class-of-service or quality-of-service parameters. The configuration file is used to initialize the network device to allow the desired service level agreement to be used with the network address from the address pool.

Another aspect of the invention includes a method for enforcing service level agreements. A data stream from an external network is received on a cable modem termination system. The cable modem termination system determines if the data stream should be managed with a service level agreement. If so, the data stream is regulated using one or more parameters from the service level agreement.

Another aspect of the invention includes a method for monitoring and regulating data transmission using service level agreements. A cable modem termination system monitors and regulates data transmission rates using service level agreements from a data-link layer.

Another aspect of the invention includes a method for shaping data traffic using service level agreements. A cable modem termination system regulates data transmission rates using a first service level agreement. A request is made to regulate data transmission with a first and second service level agreement used on the same connection. Using the first and second service level agreements on the same connection may exceed a maximum data transmission rate for the connection. The cable modem termination system may adjust the data transmission rates on the connection to another data transmission rate using a third service level agreement along with the requested second service level agreement. The third service level agreement is used to provide a lower level service than provided with the first service level agreement. Adjusted Data transmission rates for the second and third service level agreements do not exceed the maximum data transmission rates on the connection.

Another aspect of the invention includes a system for enforcing service level agreements. The service level agreements are enforced using a cable modem termination system including an integral switch, cable access router and a bandwidth manager. The cable modem termination system with integral components, or just the integral components therein may be duplicated to provide a "hot back" up in case of failure and increase reliability using service level agreements. The switch switches data streams from external networks. The cable access router enforces maximum rate limits for service level agreements. The bandwidth manager provides class-of-service or quality-of-service services with policy management and detects network trends, measures network response time and generates reports. The bandwidth manager may also monitor, regulate and shape traffic based

5

on service level agreement requests at a data-link layer level. The cable modem termination system may also include an associated Dynamic Host Configuration Protocol Server to allocate network addresses from an address pool associated with a desired service level agreement.

The methods and system of the present invention may allow service level agreements to be used on a data-over-cable system without adversely affecting performance or throughput on the data-over-cable system. The methods and system of the present invention may also help provide service level agreements on a data-over-cable system in more reliable manner.

The foregoing and other features and advantages of a preferred embodiment of the present invention will be more readily apparent from the following detailed description. The detailed description proceeds with references to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention are described with reference to the following drawings, wherein:

FIG. 1 is a block diagram illustrating a cable modem system with telephony return;

FIG. 2 is a block diagram illustrating a protocol stack for a cable modem;

FIG. 3 is a block diagram illustrating a Telephony Channel Descriptor message structure;

FIG. 4 is a block diagram illustrating a Termination System Information message structure;

FIG. 5 is a block diagram illustrating a Dynamic Host Configuration Protocol message structure;

FIG. 6 is a block diagram illustrating an exemplary cable bandwidth provision system;

FIG. 7 is a flow diagram illustrating a method for providing bandwidth provisioning;

FIG. 8 is a flow diagram illustrating a method for requesting service level agreements;

FIG. 9 is a flow diagram illustrating a method for enforcing bandwidth provisioning for service level agreements;

FIG. 10 is a flow diagram illustrating a method for monitoring and regulating data transmission using service level agreements; and

FIG. 11 is a flow diagram illustrating a method for shaping data traffic using service level agreements.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

##### Exemplary Data-over-cable System

FIG. 1 is a block diagram illustrating an exemplary data-over-cable system 10. Most cable providers known in the art predominately provide uni-directional cable systems, supporting only a "downstream" data path. A downstream data path is the flow of data from a cable television network "headend" to customer premise equipment (e.g., a customer's personal computer). A cable television network headend is a central location that is responsible for sending cable signals in a downstream direction. A return path via a telephony network ("telephony return") is typically used for an "upstream" data path in uni-directional cable systems. An upstream data path is the flow of data from customer premise equipment back to the cable television network headend.

However, data-over-cable system 10 of the present invention may also provide a bi-directional data path (i.e., both

6

downstream and upstream) without telephony return as is also illustrated in FIG. 1. The present invention is not limited to a data-over-cable system with telephony return. In a data-over-cable system without telephony return, customer premise equipment or a cable modem has an upstream connection to the cable modem termination system via a cable television connection, a wireless connection, a satellite connection, or a connection via other technologies to send data upstream to the cable modem termination system. Data-over-cable system 10 includes a Cable Modem Termination System ("CMTS") 12 connected to a cable television network 14, hereinafter cable network 14. FIG. 1 illustrates one CMTS 12. However, data-over-cable system 10 can include multiple CMTS 12.

In one preferred embodiment of the present invention, the CMTS 12 is a Total Control hub by 3Com Corporation of Santa Clara, Calif., with a cable modem termination unit. A Total Control hub is a chassis with multiple networking cards connected by a common bus. An exemplary Total Control hub is described in U.S. Pat. No. 5,528,595, granted to Dale M. Walsh et al., and incorporated in herein by reference. However, the CMTS 12 could also be another network servers including those by Lucent Technologies of Murray Hill, N.J., Livingston Enterprises, Inc. of Pleasanton, Calif., Ascend Communications of Alameda, Calif., Cisco Systems, Inc., of San Jose, Calif. and others.

The Cable network 14 includes cable television networks such as those provided by Comcast Cable Communications, Inc., of Philadelphia, Pa., Cox Communications, or Atlanta, Ga., Tele-Communications, Inc., of Englewood Colo., Time-Warner Cable, of Marietta, Ga., Continental Cablevision, Inc., of Boston, Mass., and others. The cable network 14 is connected to a Cable Modem ("CM") 16 with a downstream cable connection. The CM 16 is any cable modem such as those provided by 3Com Corporation of Santa Clara, Calif., Motorola Corporation of Arlington Heights, Ill., Hewlett-Packard Co. of Palo Alto, Calif., Bay Networks of Santa Clara, Calif., Scientific-Atlanta, of Norcross, Ga., General Instruments of Horsham, Pa., and others. FIG. 1 illustrates one CM 16. However, in a typical data-over-cable system, tens or hundreds of thousands of the CMs 16 are connected to the CMTS 12. The CM 16 is connected to Customer Premise Equipment ("CPE") 18 such as a personal computer system via a Cable Modem-to-CPE Interface ("CMCI") 20.

One CPE 18 is illustrated in FIG. 1. However, the CM 16 may have multiple CPEs 18 attached (Not illustrated in FIG. 1). In one preferred embodiment of the present invention, the CM 16 is connected to a Public Switched Telephone Network ("PSTN") 22 with an upstream telephony connection. The PSTN 22 includes those public switched telephone networks provided by AT&T, Regional Bell Operating Companies (e.g., Ameritech, U.S. West, Bell Atlantic, Southern Bell Communications, Bell South, NYNEX, and Pacific Telesis Group), GTE, Sprint, MCI and others. The upstream telephony connection is any of a standard telephone line connection, Integrated Services Digital Network ("ISDN") connection, Asymmetric Digital Subscriber Line ("ADSL") connection, a wireless connection or other telephony connection. The PSTN 22 is connected to a Telephony Remote Access Concentrator ("TRAC") 24.

In another preferred embodiment of the present invention, in a data-over-cable system without telephony return, the CM 16 has an upstream connection to the CMTS 12 via a cable television connection, a wireless connection, a satellite connection, or a connection via other technologies to send data upstream outside of the telephony return path. An upstream cable television connection via cable network 14 is

also illustrated in FIG. 1. In such an embodiment, the CMTS 12 may also provide data streams involving voice, video or data information to a CM 16, or CPE 18 from the PSTN 22 even when a telephony return path is not used.

FIG. 1 illustrates a telephony modem integral to the CM 16. In another embodiment of the present invention, the telephony modem is a separate modem unit external to the CM 16 used specifically for connecting with the PSTN 22. A separate telephony modem includes a connection to the CM 16 for exchanging data. In yet another embodiment of the present invention, the CM 16 includes functionality to connect only to the cable network 14 and receives downstream signals from the cable network 14 and sends upstream signals to the cable network 14 without using the telephony return path. The present invention is not limited to cable modems used in a data-over-cable system with telephony return.

In one preferred embodiment of the present invention of the telephony return, the TRAC 24 is a Total Control Telephony Hub by 3Com Corporation of Santa Clara, Calif. However, the TRAC 24 could also be a telephony hub including those by Lucent Technologies of Murray Hill, N.J., Livingston Enterprises, Inc. of Pleasanton, Calif., Ascend Communications of Alameda, Calif. and others.

The CMTS 12 and the TRAC 24 may be at a "headend" of cable system 10, or the TRAC 24 may be located elsewhere and have routing associations to the CMTS 12. The CMTS 12 and the TRAC 24 together are called a "Telephony Return Termination System" ("TRTS") 26. The TRTS 26 is illustrated by a dashed box in FIG. 1. The CMTS 12 and the TRAC 24 make up the TRTS 26 whether or not they are located at the headend of cable network 14. The TRAC 24 may be located in a different geographic location from the CMTS 12: Content servers, operations servers, administrative servers and maintenance servers used in data-over-cable system 10 (not shown in FIG. 1) may also be in different locations. Access points to the data-over-cable system 10 are connected to one or more of the CMTS 12, or cable headend access points. Such configurations may be "one-to-one", "one-to-many," or "many-to-many," and may be interconnected to other Local Area Networks ("LANs") or Wide Area Networks ("WANs").

The TRAC 24 is connected to a data network 28 (e.g., the Internet, an intranet or other LAN) by a TRAC-Network System Interface 30 ("TRAC-NSI"). The CMTS 12 is connected to data network 28 by a CMTS-Network System Interface ("CMTS-NSI") 32. The CMTS 12 may send and receive data to/from a CM16 or a CPE 18 via the PSTN 22 even if telephony return is not used. The present invention is not limited to data-over-cable system 10 illustrated in FIG. 1, and more or fewer components, connections and interfaces could also be used. The present invention may also be used in a data-over-cable system 10 with or without telephony return.

#### Network Device Protocol Stack

FIG. 2 is a block diagram illustrating a protocol stack 36 for network devices, in data-over-cable system 10. In one exemplary preferred embodiment of the present invention, network devices in the data-over-cable system 10 are compliant with Data-Over-Cable-Service-Interface-Specification ("DOCSIS") standards from the Multimedia Cable Network Systems ("MCNS"), incorporated herein by reference. The DOCSIS standards can be found on the World Wide Web at the Universal Resource Locator ("URL") "www.cablemodem.com." However, other standards may also be used and the present invention is not limited to network devices compliant with DOCSIS and MCNS. How-

ever FIG. 2 illustrates the downstream and upstream protocols used, for example, in the CM 16. As is known in the art, the Open System Interconnection ("OSI") model is used to describe computer networks. The OSI model consists of seven layers including from lowest-to-highest, a physical, data-link, network, transport, session, presentation and application layer. The physical layer transmits bits over a communication link. The data link layer transmits error free frames of data. The network layer transmits and routes data packets.

For downstream data transmission, network devices including the CM 16 are connected to cable network 14 in a physical layer 38 via a Radio Frequency ("RF") Interface 40. In a preferred embodiment of the present invention, RF Interface 40 has an operation frequency range of 50 Mega-Hertz ("MHz") to 1 Giga-Hertz ("GHz") and a channel bandwidth of 6 MHz. However, other operation frequencies may also be used and the invention is not limited to these frequencies. The RF interface 40 uses a signal modulation method, such as Quadrature Amplitude Modulation ("QAM"). As is known in the art, QAM is used as a means of encoding digital information over radio, wire, or fiber optic transmission links. QAM is a combination of amplitude and phase modulation and is an extension of multiphase phase-shift-keying. QAM can have any number of discrete digital levels typically including 4, 16, 64 or 256 levels. In one embodiment of the present invention, QAM-64 is used in the RF interface 40. However, other operating frequencies and modulation methods could also be used (e.g., Quadrature Phase Shift Keying ("QPSK") modulation). For more information on the RF interface 40 see the Institute of Electrical and Electronic Engineers ("IEEE") standard 802.14 for cable modems incorporated herein by reference. IEEE standards can be found on the World Wide Web at the URL "www.ieee.org." However, other RF interfaces 40 could also be used and the present invention is not limited to IEEE 802.14 (e.g., RF interfaces from MCNS) and others could also be used).

Above the RF interface 40 in a data-link layer 42 is a Medium Access Control ("MAC") layer 44. As is known in the art, the MAC layer 44 controls access to a transmission medium via physical layer 38. For more information on the MAC layer protocol 44 see IEEE 802.14 for cable modems. However, other MAC layer protocols 44 could also be used and the present invention is not limited to IEEE 802.14 MAC layer protocols (e.g., MCNS MAC layer protocols and others could also be used).

Above the MAC layer 44 is an optional link security protocol stack 46. The link security protocol stack 46 prevents unauthorized users from making a data connection from cable network 14. The RF interface 40 and the MAC layer 44 can also be used for an upstream cable connection in a data-over-cable system 10 without telephony return.

For upstream data transmission with telephony return, the CM 16 is connected to the PSTN 22 in physical layer 38 via telephony interface 48. The International Telecommunications Union-Telecommunication Standardization Sector ("ITU-T", formerly known as the CCITT) defines standards for communication devices identified by "V.xx" series where "xx" is an identifying number. ITU-T standards can be found on the World Wide Web at the URL "www.itu.ch."

In one embodiment of the present invention, ITU-T V.34 is used as telephony interface 48. As is known in the art, ITU-T V.34 is commonly used in the data link layer for modem communications and currently allows data rates as high as 33,600 bits-per-second ("bps"). For more information see the ITU-T V.34 standard. However, modem inter-



faces (e.g., V.90) or other telephony interfaces could also be used. For example, an Asymmetric Digital Subscriber Link ("ADSL"), an Integrated Services Digital Network ("ISDN") or a wireless telephony interface could also be used for the telephony interface 48.

Above the telephony interface 48, in the data link layer 42, is a Point-to-Point Protocol ("PPP") layer 50, hereinafter PPP 50. As is known in the art, PPP 50 is used to encapsulate network layer datagrams over a serial communications link. For more information on PPP 50 see Internet Engineering Task Force ("IETF") Request for Comments ("RFC"), RFC-1661, RFC-1662 and RFC-1663, incorporated herein by reference. Information for IETF RFCs can be found on the World Wide Web at URLs "ds.internic.net" or "www.ietf.org."

Above both the downstream and upstream protocol layers in a network layer 52 is an Internet Protocol ("IP") layer 54. IP layer 54, hereinafter IP 54, roughly corresponds to OSI layer 3, the network layer, but is typically not defined as part of the OSI model. As is known in the art, IP 54 is a routing protocol designed to route traffic within a network or between networks. For more information on IP 54 see, RFC-791, incorporated herein by reference.

Internet Control Message Protocol ("ICMP") layer 56 is used for network management. The main functions of ICMP layer 56, hereinafter ICMP 56, include error reporting, reachability testing (e.g., "pinging"), congestion control, route-change notification, performance, subnet addressing and others. Since IP 54 is an unacknowledged protocol, datagrams may be discarded and ICMP 56 is used for error reporting. For more information on ICMP 56 see, RFC-792, incorporated herein by reference.

Above IP 54 and ICMP 56 is a transport layer 58 with a User Datagram Protocol layer 60 ("UDP"). UDP layer 60, hereinafter UDP 60, roughly corresponds to OSI layer 4, the transport layer, but is typically not defined as part of the OSI model. As is known in the art, UDP 60 provides a connectionless mode of communications with datagrams. For more information on UDP 60 see RFC-768, incorporated herein by reference. Transmission Control Protocol ("TCP") may also be used in the transport layer 58. For more information on TCP see RFC-793, incorporated by reference.

Above the network layer are a Simple Network Management Protocol ("SNMP") layer 62, Trivial File Transfer Protocol ("TFTP") layer 64, Dynamic Host Configuration Protocol ("DHCP") layer 66 and a UDP manager 68. SNMP layer 62 is used to support network management functions. For more information on SNMP layer 62 see RFC-1157, incorporated herein by reference. TFTP layer 64 is a file transfer protocol used to download files and configuration information. For more information on TFTP layer 64 see RFC-1350, incorporated herein by reference. The DHCP layer 66 is a protocol for passing configuration information to hosts on an IP 54 network. For more information on the DHCP layer 66 see, RFC-1541, and RFC-2131 and RFC-2132, incorporated herein by reference. UDP manager 68 distinguishes and routes packets to an appropriate service (e.g., a virtual tunnel). More or few protocol layers could also be used with data-over-cable system 10.

The CM 16 supports transmission and reception of IP 54 datagrams as specified by RFC-791. The CMTS 12 and the TRAC 24 may also perform filtering of IP 54 datagrams. The CM 16 is also configurable for IP 54 datagram filtering to restrict the CM 16 and the CPE 18 to the use of only their assigned IP 54 addresses. The CM 16 is configurable for IP 54 datagram UDP 60 port filtering (i.e., deep filtering).

The CM 16 forwards IP 54 datagrams destined to an IP 54 unicast address across the cable network 14 or the PSTN 22.

Some routers have security features intended to filter out invalid users who alter or masquerade packets as if sent from a valid user. Since routing policy is under the control of network operators, such filtering is a vendor specific implementation. For example, dedicated interfaces (i.e., Frame Relay) may exist between the TRAC 24 and/or the CMTS 12 which preclude filtering, or various forms of virtual tunneling and reverse virtual tunneling could be used to virtually source upstream packets from the CM 16. For more information on virtual tunneling, see Level 2 Tunneling Protocol ("L2TP") or Point-to-Point Tunneling Protocol ("PPTP") in IETF draft documents by Kory Hamzeh (IETF draft documents are precursors to IETF RFCs and are works in progress), incorporated herein by reference.

The CM 16 also forwards IP 54 datagrams destined to an IP 54 multicast address across the cable network 14 or the PSTN 22. The CM 16 is configurable to keep IP 54 multicast routing tables and to use group membership protocols. The CM 16 is also capable of IP 54 tunneling upstream through the telephony path. A CM 16 that wants to send a multicast packet across a virtual tunnel will prepend another IP 54 header, set the destination address in the new header to be the unicast address of the CMTS 12 at the other end of the tunnel, and set the IP 54 protocol field to be four, which means the next protocol is IP 54.

The CMTS 12 at the other end of the virtual tunnel receives the packet, strips off the encapsulating IP 54 header, and forwards the packet as appropriate. A broadcast IP 54 capability is dependent upon the configuration of the direct linkage, if any, between the TRAC 24 and the CMTS 12. The CMTS 12, the CM 16, and the TRAC 24 are capable of routing IP 54 datagrams destined to an IP 54 broadcast address which is across the cable network 14 or the PSTN 22 if so configured. The CM 16 is configurable for IP 54 broadcast datagram filtering.

An operating environment for the CMTS 12, the CM 16, the CPE 18, the TRAC 24 and other network devices of the present invention includes a processing system with at least one high speed Central Processing Unit ("CPU") and a memory system. In accordance with the practices of persons skilled in the art of computer programming, the present invention is described below with reference to acts and symbolic representations of operations or instructions that are performed by the processing system, unless indicated otherwise. Such acts and operations or instructions are sometimes referred to as being "computer-executed", or "CPU executed."

It will be appreciated that the acts and symbolically represented operations or instructions include the manipulation of electrical signals by the CPU. An electrical system with data bits causes a resulting transformation or reduction of the electrical signal representation, and the maintenance of data bits at memory locations in the memory system to thereby reconfigure or otherwise alter the CPU's operation, as well as other processing of signals. The memory locations where data bits are maintained are physical locations that have particular electrical, magnetic, optical, or organic properties corresponding to the data bits.

The data bits may also be maintained on a computer readable medium including magnetic disks, optical disks, organic disks, and any other volatile or non-volatile mass storage system readable by the CPU. The computer readable medium includes cooperating or interconnected computer readable media, which exist exclusively on the processing system or is distributed among multiple interconnected processing systems that may be local or remote to the processing system.

## Initialization of a Cable Modem

When the CM 16 is initially powered on, if telephony return is being used, the CM 16 will receive a Telephony Channel Descriptor ("TCD") from the CMTS 12 that is used to provide dialing and access instructions on downstream channels via cable network 14. Information in the TCD is used by the CM 16 to connect to the TRAC 24. The TCD is transmitted as a MAC 44 management message with a management type value of TRI\_TCD at a periodic interval (e.g., every 2 seconds). To provide for flexibility, the TCD message parameters are encoded in a Type/Length/Value ("TLV") form. However, other encoding techniques could also be used. FIG. 3 is a block diagram illustrating a TCD message structure 70 with MAC 44 management header 72 and Service Provider Descriptor(s) ("SPD") 74 encoded in TLV format. SPDs 74 are compound TLV encodings that define telephony physical-layer characteristics that are used by the CM 16 to initiate a telephone call. The SPD 74 is a TLV-encoded data structure that contains sets of dialing and access parameters for the CM 16 with telephony return. The SPD 74 is contained within TCD message 70. There may be multiple SPD 74 encodings within a single TCD message 70. There is at least one SPD 74 in the TCD message 70. The SPD 74 parameters are encoded as SPD-TLV tuples. The SPD 74 contains the parameters shown in Table 1 and may contain optional vendor specific parameters. However, more or fewer parameters could also be used in the SPD 74.

TABLE 1

SPD 74 Parameter	Description
Factory Default Flag	Boolean value, if TRUE(1), indicates a SPD which should be used by the CM 16.
Service Provider Name	This parameter includes the name of a service provider. Format is standard ASCII string composed of numbers and letters.
Telephone Numbers	These parameters contain telephone numbers that the CM 16 uses to initiate a telephony modem link during a login process. Connections are attempted in ascending numeric order (i.e., Phone Number 1, Phone Number 2 . . . ). The SPD contains a valid telephony dial string as the primary dial string (Phone Number 1), secondary dial-strings are optional. Format is ASCII string(s) composed of: any sequence of numbers, pound "#", and star "*" keys and a comma character "," that is used to indicate a two second pause in dialing.
Connection Threshold	The number of sequential connection failures before indicating connection failure. A dial attempt that does not result in an answer and connection after no more than ten rings is considered a failure. The default value is one.
Login User Name	This contains a user name the CM 16 will use in an authentication protocol over the telephone link during the initialization procedure. Format is a monolithic sequence of alphanumeric characters in an ASCII string composed of numbers and letters.
Login Password	This contains a password that the CM 16 will use during authentication over a telephone link during the initialization procedure. Format is a monolithic sequence of alphanumeric characters in an ASCII string composed of numbers and letters.
DHCP 66 Authenticate	Boolean value, reserved to indicate that the CM 16 uses a specific indicated DHCP 66 Server (see next parameter) for

TABLE 1-continued

SPD 74 Parameter	Description
DHCP 66 Server	a DHCP 66 Client and BOOTP Relay Process when TRUE (one). The default is FALSE (zero) which allows any DHCP 66 Server. IP 54 address value of a DHCP 66 Server the CM 16 uses in the DHCP 66 Client and BOOTP Relay Process when the DHCP 66 Authenticate attribute is TRUE(1) and this attribute is present. The default value is integer zero.
RADIUS Realm	The realm name is a string that defines a Remote Authentication Dial In User Service ("RADIUS") server domain. Format is a monolithic sequence of alphanumeric characters in an ACSII string composed of numbers and letters.
PPP 50 Authentication	This parameter instructs the telephone modem which authentication procedure to perform over the telephone link.
Demand Dial Timer	This parameter indicates time (in seconds) of inactive networking time that will be allowed to elapse before hanging up a telephone connection at CM 16. If this optional parameter is not present, or set to zero, then the demand dial feature is not activated. The default value is zero.
Vendor Specific Extensions	Optional vendor specific extensions.

A Termination System Information ("TSI") message is transmitted by the CMTS 12 at periodic intervals (e.g., every 2 seconds) to report CMTS 12 information to the CM 16 whether or not telephony return is used. The TSI message is transmitted as a MAC 44 management message. The TSI provides a CMTS 12 boot record in a downstream channel to the CM 16 via cable network 14. Information in the TSI is used by the CM 16 to obtain information about the status of the CMTS 12. The TSI message has a MAC 44 management type value of TRI\_TSI.

FIG. 4 is a block diagram of a TSI message structure 76. The TSI message structure 76 includes a MAC 44 management header 78, a downstream channel IP address 80, a registration IP address 82, a CMTS 12 boot time 84, a downstream channel identifier 86, an epoch time 88 and vendor specific TLV encoded data 90.

A description of the fields of TSI message 76 are shown in Table 2. However, more or fewer fields could also be used in TSI message 76.

TABLE 2

TSI 76 Parameter	Description
Downstream Channel IP Address 80	This field contains an IP 54 address of the CMTS 12 available on the downstream channel this message arrived on.
Registration IP Address 82	This field contains an IP 54 address the CM 16 sends its registration request messages to. This address MAY be the same as the Downstream Channel IP 54 address.
CMTS Boot Time 84	Specifies an absolute-time of a CMTS 12 recorded epoch. The clock setting for this epoch uses the current clock time with an unspecified accuracy. Time is represented as a 32 bit binary number.

TABLE 2-continued

TSI 76 Parameter	Description
Downstream Channel ID 86	A downstream channel on which this message has been transmitted. This identifier is arbitrarily chosen by CMTS 12 and is unique within the MAC 44 layer.
Epoch 88	An integer value that is incremented each time the CMTS 12 is either re-initialized or performs address or routing table flush.
Vendor Specific Extensions 90	Optional vendor extensions may be added as TLV encoded data.

If telephony return is being used, after receiving the TCD 70 message and the TSI message 76, the CM 16 continues to establish access to data network 28 (and resources on the network) by first dialing into the TRAC 24 and establishing a telephony PPP 50 session. Upon the completion of a successful PPP 50 connection, the CM 16 performs PPP 50 Link Control Protocol ("LCP") negotiation with the TRAC 24.

Once LCP negotiation is complete, the CM 16 requests Internet Protocol Control Protocol ("IPCP") address negotiation for an upstream telephony return path. For more information on IPCP see RFC-1332, incorporated herein by reference. During IPCP negotiation, the CM 16 negotiates, via PPP 50, an IP 54 address with the TRAC 24 for sending IP 54 data packet responses back to data network 28 via the TRAC 24.

When the CM 16 has established an upstream IP 54 link to TRAC 24, it begins "upstream" communications to the CMTS 12 via the DHCP layer 66 to complete a virtual data connection by attempting to discover network host interfaces available on the CMTS 12 (e.g., IP 54 host interfaces for a virtual IP 54 connection). The virtual data connection allows the CM 16 to receive data from data network 28 via the CMTS 12 and cable network 14, and send return data to data network 28 via TRAC 24 and PSTN 22. The CM 16 must first determine an address of a network host interface (e.g., an IP 54 interface) associated with the CMTS 12 that can be used by data network 28 to send data to the CM 16. In one preferred embodiment of the present invention, the CM 16 has only a downstream cable connection from the CMTS 12 and will obtain a connection address to the data network 28 using an upstream telephony connection to the TRAC 24. In another preferred embodiment of the present invention, the CM 16 will obtain a connection address to the cable network using an upstream cable connection to the CMTS 12.

An exemplary data path through cable system 10 is illustrated in Table 3. However other data paths could also be used and the present invention is not limited to the data paths shown in Table 3. For example, the CM 16 may send data upstream back through the cable network 14 (e.g., the CM 16 to cable network 14 to the CMTS 12 and to the data network 28 through CMTS NSI 32) and not use the PSTN 22, the TRAC 24, or the telephony return upstream path at all.

TABLE 3

- 1 An IP 54 datagram from data network 28 destined for the CM 16 arrives on the CMTS-NSI 32 and enters the CMTS 12.
- 2 CMTS 12 encodes the IP 54 datagram in a cable data frame, passes it to MAC 44 and transmits it "downstream" to RF interface 40 on the CM 16 via cable network 14.

TABLE 3-continued

- 3 CM 16 recognizes the encoded IP 54 datagram in MAC layer 44 received via RF interface 40.
- 4 CM 16 responds to the cable data frame and encapsulates a response IP 54 datagram in a PPP 50 frame and transmits it "upstream" with telephony interface 48 via the PSTN 22 to TRAC 24.
- 5 TRAC 24 decodes the IP 54 datagram and forwards it via TRAC-NSI 30 to a destination on the data network 28.
- 6 In a two-way cable system, the CM 16 encapsulates a response IP 54 datagram in a cable data frame passes it to MAC 44 and transmits it "upstream" via CM 16 RF interface 40 to the CMTS 12 via cable network 14.
- 7 In a two-way cable system, the CMTS 12 decodes the IP 54 datagram from the cable frame and forwards it via TRAC-NSI 32 to a destination on the data network 28.

#### Dynamic Network Host Configuration on a Data-over-cable System

As was illustrated in FIG. 2, the CM 16 includes a Dynamic Host Configuration Protocol ("DHCP") layer 66, hereinafter the DHCP 66. The DHCP 66 is used to provide configuration parameters to hosts on a network (e.g., an IP 54 network). The DHCP 66 consists of two components: a protocol for delivering host-specific configuration parameters from a DHCP 66 server to a host and a mechanism for allocation of network host addresses to hosts. DHCP 66 is built on a client-server model, where designated DHCP 66 servers allocate network host addresses and deliver configuration parameters to dynamically configured network host clients.

FIG. 5 is a block diagram illustrating an exemplary DHCP 66 message structure 108. The format of the DHCP 66 messages is based on the format of BOOTstrap Protocol ("BOOTP") messages described in RFC-951 and RFC-1542, incorporated herein by reference. From a network host client's point of view, the DHCP 66 is an extension of the BOOTP mechanism. This behavior allows existing BOOTP clients to interpret with the DHCP 66 servers without requiring any change to network host clients' BOOTP initialization software. The DHCP 66 provides persistent storage of network parameters for network host clients.

To capture BOOTP relay agent behavior described as part of the BOOTP specification and to allow interoperability of existing BOOTP clients with the DHCP 66 servers, the DHCP 66 server uses a BOOTP message format. Using BOOTP relaying agents eliminates the necessity of having a DHCP 66 server on each physical network segment.

DHCP 66 message structure 108 includes an operation code field 110 ("op"), a hardware address type field 112 ("htype"), a hardware address length field 114 ("hlen"), a number of hops field 116 ("hops"), a transaction identifier field 118 ("xid"), a seconds elapsed time field 120 ("secs"), a flags field 122 ("flags"), a client IP address field 124 ("ciaddr"), a your IP address field 126 ("yiaddr"), a server IP address field 128 ("siaddr"), a gateway/relay agent IP address field 130 ("giaddr"), a client hardware address field 132 ("chaddr"), an optional server name field 134 ("sname"), a boot file name field 136 ("file") and an optional parameters field 138 ("options"). Descriptions for an exemplary DHCP 66 message 108 fields are shown in Table 4a.

TABLE 4a

DHCP 66 Parameter	Description
OP 110	Message op code/message type. 1 = BOOTREQUEST, 2 = BOOTREPLY.
HTYPE 112	Hardware address type (e.g., '1' = 10 Mbps Ethernet).
HLEN 114	Hardware address length (e.g. '6' for 10 Mbps Ethernet).
HOPS 116	Client sets to zero, optionally used by relay-agents when booting via a relay- agent.
XID 118	Transaction ID, a random number chosen by the client, used by the client and server to associate messages and responses between a client and a server.
SECS 120	Filled in by client, seconds elapsed since client started trying to boot.
FLAGS 122	Flags including a BROADCAST bit.
CIADDR 124	Client IP address; filled in by client in DHCPREQUEST if verifying previously allocated configuration parameters.
YIADDR 126	'Your'(client) IP address.
SIADDR 128	IP 54 address of next server to use in bootstrap; returned in DHCPPOFFER, DHCPACK and DHCPNAK by server.
GIADDR 130	Gateway relay agent IP 54 address, used in booting via a relay-agent.
CHADDR 132	Client hardware address (e.g., MAC layer 44 address).
SNAME 134	Optional server host name, null terminated string.
FILE 136	Boot file name, terminated by a null string.
OPTIONS 138	Optional parameters.

The DHCP 66 message structure shown in FIG. 5 is used to discover IP 54 network host interfaces in data-over-cable system 10. A network host client (e.g., the CM 16 or the CPE 18) uses the DHCP 66 to dynamically acquire or verify an IP 54 address and network parameters whenever the network parameters may have changed. Table 4b illustrates a typical use of the DHCP 66 protocol to discover a network address from a network host client like the CM 16 or the CPE 18.

TABLE 4b

1. A network host client broadcasts a DHCPDISCOVER message on its local physical subnet. The DHCPDISCOVER message may include options that suggest values for a network host interface address. BOOTP relay agents may pass the message on to DHCP 66 servers not on the same physical subnet.
2. DHCP servers may respond with a DHCPPOFFER message that includes an available network address in the 'yiaddr' field (and other configuration parameters in DHCP 66 options) from a network host interface. DHCP 66 servers unicasts the DHCPPOFFER message to the network host client (using the DHCP/BOOTP relay agent if necessary) if possible, or may broadcast the message to a broadcast address (preferably 255.255.255.255) on the client's subnet.
3. The network host client receives one or more DHCPPOFFER messages from one or more DHCP 66 servers. The network host client may choose to wait for multiple responses.
4. The network host client chooses one DHCP 66 server with an associated network host interface from which to request configuration parameters, based on the configuration parameters offered in the DHCPPOFFER messages.
5. The network host client sends a DHCPREQUEST message to the selected DHCP 66 server to request one available network address and configuration parameters from a selected DHCP 66 server.
6. The selected DHCP 66 server responds to the network host client with a DHCPACK message indicating acknowledgment of the use of the available network address and configuration parameters.

The DHCP 66 discovery process for the CM 16 and the CPE 18 in a data-over-cable system 10 differs when tele-

phony return is used because of the upstream telephony return path and TRAC 24 connection to the CMTS 12 from the CM 16 and/or CPE 18. The DHCP 66 discovery process for a data-over-cable system with telephony return is described in co-pending application Ser. Nos. 09/018,784, 09/018,401 and 09/018,814.

#### Connection Services in a Data-over-cable System

During initialization, individual cable modems 16 may request upstream and downstream connections with a different Class-of-Service ("CoS") or Quality of Service ("QoS") to/from the CMTS 12 on the cable network 14. As is known in the art, CoS provides a reliable (i.e., error free, in sequence, with no loss of duplication) transport facility independent of the QoS. QoS collectively specifies the performance of the network service that a device expects on a network. The CoS and QoS connections are requested with a registration message sent from CM 16 to CMTS 12. Exemplary methods for providing CoS and QoS in a data-over-cable system in via the data-link layer 42 are described in co-pending application Ser. Nos. 09/079,323 and 09/079,322, which are both incorporated herein by reference. However, the present invention is not limited to these methods for providing CoS or QoS in the data-link layer 42 and other methods and other layers can also be used for providing CoS or QoS on a data-over-cable system. Exemplary Data-over-cable System with Service Level Agreements

In one exemplary preferred embodiment of the present invention, CoS and QoS are preferably provided in a two-way data-over-cable system using service level agreements as is illustrated in FIG. 6. However, the present invention may also be used in a data-over-cable system with telephony return. FIG. 6 is a block diagram illustrating an exemplary data-over-cable system 140 for using service level agreements. The exemplary data-over-cable system 140 includes a CMTS 12, with a switch 142, a cable access router 144, a bandwidth manager 146, a bandwidth provisioning server 148 and a DHCP 66 server 150. However, more or fewer system components can also be used and the present invention is not limited to the components illustrated in FIG. 6.

In one exemplary preferred embodiment of the present invention, the switch 142, the cable access router 144 and the bandwidth manager 146 are integral to CMTS 12. In such an embodiment the CMTS 12 with integral components acts as a bridging device that enforces CoS and QoS, between the cable network 14 and external networks such as the data network 28 and the PSTN 22. The switch 142, cable access router 144 and the bandwidth manager 146 components are included as additional printed circuit boards in a Total Control hub with a cable modem termination unit by 3Com Corporation of Santa Clara, Calif. However, the integral CMTS 12 could also be another network server including those by Lucent Technologies of Murray Hill, N.J., Livingston Enterprises, Inc. of Pleasanton, Calif., Ascend Communications of Alameda, Calif., Cisco Systems, Inc., of San Jose, Calif., and others. The switch 142, cable access router 144, and/or bandwidth manager 146, can also be used as separate, non-integral components associated with the CMTS 12.

In one preferred embodiment of the present invention, the CMTS 12 with integral components including the switch 142, the cable access router 144, and the bandwidth manager 146 is duplicated to provide a "hot" back-up in case of failure. A first CMTS 12 and second CMTS' 12 are on-line simultaneously and operate in parallel with only one in control and the other one in hot standby. The two units communicate with one another using a "keep-alive" signal.

17

If the primary CMTS 12 fails, the redundant unit CMTS' 12 immediately takes over, ideally without loss of any service. The units are made redundant by duplication of control messaging and a monitor that determines if/when a switch-over between the active and stand-by units is necessary.

In another embodiment of the present invention, the redundant units are operated in a serial manner. In such an embodiment, the two units are cross-connected with a heart-beat controlled shunt on Ethernet ports. The serial mode is "active-active" as opposed to the parallel mode which is "active-standby."

In another embodiment of the present invention, any of the integral components in the CMTS 12 may be duplicated to provide a hot back-up in case of failure. In such an embodiment, the individual integral components instead after whole CMTS 12 are duplicated.

Thus, the CMTS 12 with integral components is a redundant "bridge" that enforces CoS and QoS, between the cable network 14 and external networks without adversely affecting system performance of throughput. The redundant CMTS 12 with internal components helps provide reliable CoS and QoS and reduces the risks of using a single network device to provide CoS and QoS service. The CMTS 12 with integral components also provides access routing for any of Asynchronous Transfer Mode ("ATM"), Asymmetric Digital Subscriber Lines ("ADSL"), Voice over Internet Protocol ("VoIP"), IP 54, etc. or cable data television streams to CMs 16 and CPEs 18 on the cable network 14.

In one preferred embodiment of the present invention, the switch 142 is a telephony or data switch capable of switching voice, video and/or data streams from the TRAC 24 and the data network 28 to the CMTS 12. The switch 142 is any of those provided by 3Com, Lucent, Livingston, Ascend, Cisco, or others. The cable access router 142 is a router that can enforce a Maximum Rate Limit ("MRL") on both downstream and upstream traffic to/from the CMTS 12. The cable access router 142 is any of those provided by 3Com, Cisco and others.

The bandwidth manager 146 provides CoS and QoS services with policy management via the CMTS 12. The bandwidth manager 146 detects network trends, measures network response time and generates CoS and QoS reports. These network response measurements allow performance measurements and the taking of appropriate bandwidth actions to set acceptability standards for average peak cable network usage and cable link utilization.

The bandwidth provisioning server 148 provides a Graphical User Interface ("GUI") for bandwidth manager 146 administration, user set up, bandwidth usage monitoring, usage data collection, etc. The DHCP 66 server 150 dynamically assigns IP 54 addresses to the CMs 16 and CPEs 18.

#### Providing Service Level Agreements

FIG. 7 is a flow diagram illustrating a Method 152 for providing bandwidth provisioning. At Step 154, one or more Service Level Agreements ("SLAs") are created. As is known in the art SLAs are used to determine what policies, programs and/or data transmission rates will be offered to customers. The one or more service level agreements include one or more class-of-service or quality-of-service parameters for a desired class-of-service or quality-of-service. At Step 156, one or more pools of network addresses are assigned to the one or more service level agreements. At Step 158, a bandwidth manager associated with a cable modem termination system is notified of the one or more service level agreements and the one or more pools of network addresses. At Step 160, the one or more pools of

18

network addresses are assigned to a network address server. The network address server assigns network addresses from the one or more pools to network devices requesting desired service level agreements on the data-over-cable system. At Step 162, one or more configuration files for the one or more service level agreements are created. The one or more configuration files are used to initialize a network device with a desired service level agreement on the data-over-cable system. At Step 164, data transmission information from the configuration files are loaded in a cable access router. The cable access router uses the data transmission information to enforce CoS or QoS parameters bandwidth parameters to enforce maximum rate limits for a desired service level agreement.

In one exemplary preferred embodiment of the present invention, Method 152 is used on the exemplary data-over-cable system 140. However, the present invention is not limited to this implementation, and other data-over-cable systems can also be used. In such an embodiment, at Step 154, one or more service level agreements are created. The one or more service level agreements include one or more class-of-service or quality-of-service parameters for a desired class-of-service or quality-of-service.

Table 5 illustrates exemplary service level agreements. However, the present invention is not limited to the service level agreements illustrated in Table 5 and other service level agreements can also be used.

TABLE 5

Plan	CIR Down	MBR Down	CIR Up	MBR Up	Prior-ity	Time
Biz Gold	1024K	1544K	512K	512K	1	M-F 8-6
Biz Silver	512K	800K	256K	256K	2	M-F 8-6
Gold	256K	512K	128K	128K	3	ALL
Silver	128K	256K	64K	64K	4	ALL
Premium	64K	128K	40K	40K	5	ALL

In Table 5, "plan" refers to a service level agreement name, "CIR" indicates a guaranteed Committed Information Rate, "MBR" indicates a Maximum Burst Rate, "priority" indicates a priority assigned to the service level agreement (e.g., 1=highest priority, 5=lowest priority) and "time" indicates a time of day the service level agreement is available.

Table 6 illustrates two exemplary CoS service classes (class 1 and class 5) used in service level agreements Biz Gold and Premium (Table 5) respectively. However, more or fewer classes of service along with other identifying values could also be used. CoS service classes 2, 3 and 4 include similar parameters. CoS parameters include maximum downstream data rates in bits-per-second ("bps"), maximum upstream data rate in bps, upstream channel priority, guaranteed minimum data rates in bps, guaranteed maximum data rate in bps and other parameters. Table 6 illustrates CoS values as a value sub-Type, Length Value for a TLV format. However, other layouts and format can also be used.

TABLE 6

Type	Length	Value (sub)type	Length	Value	Description of Value
4	28	1	1	5	CoS-5
4	28	2	4	128,000	Maximum forward rate of 128K bps

TABLE 6-continued

Type	Length	Value (sub)type	Length	Value	Description of Value
4	28	3	4	40,000	Maximum return rate of 40K bps
4	28	4	1	5	Priority of 5
4	28	5	4	64,000	Minimum guaranteed rate of 64 kbps
4	28	6	2	10	Maximum transmission burst of 10 cable network mini-slots
4	28	1	1	1	CoS-1
4	28	2	4	1,544,000	Maximum forward rate of 1544K bps
4	28	3	4	512,000	Maximum return rate of 517K bps
4	28	4	1	1	Priority of 1
4	28	5	4	1,024,000	Minimum guaranteed rate of 1024K bps
4	28	6	2	100	Maximum transmission burst of 100 cable network mini-slots

QoS parameters include transit delay expected to deliver data to a specific destination, the level of protection from unauthorized monitoring or modification of data, cost for delivery of data, expected residual error probability, the relative priority associated with the data and other parameters.

Table 7 illustrates exemplary QoS parameters as Flow Identifiers in TLV format. However, more or fewer flow identifiers can also be used.

TABLE 7

Type/Subtype	Length	Description of Value
Ax	N	Flow Class Definition Header
A0	4	Flow Class Identifier
A1	1	Flow Type
A2	1	Ethernet precedence and TOS
A3	1	ATM flow subtype
A4	6	Minimum number of bytes/sec
A5	6	Maximum number of bytes/sec
A6	N	Cell Error Ratio
A7	N	Cell Loss Ratio
A8	N	Cell Mis-insertion Rate
A9	N	Mean Cell Transfer Delay
A10	N	Cell Variation Delay
A11-A127	N	Reserved
A128-A255	N	Vendor Specific

Table 8 illustrates exemplary Type-Of-Service ("ToS") sub-TLV information for QoS parameters. However, more or fewer ToS parameters can also be used.

TABLE 8

Type of Service (TOS)	Bit-0	Bit-1	Bit-2	Bit-3	Decimal Value
Maximize Delay	1	0	0	0	1
Maximize Throughput	0	1	0	0	2

TABLE 8-continued

Type of Service (TOS)	Bit-0	Bit-1	Bit-2	Bit-3	Decimal Value
Maximize Reliability	0	0	1	0	4
Minimize Cost	0	0	0	1	8
Normal Service	0	0	0	0	0

Table 9 illustrates exemplary Flow Identifier Values (Type A0, Table 7). However, more or fewer flow identifier values can also be used.

TABLE 9

Flow Identifier Value (4-bytes)	Definition of Value
0	The packet is to be sent to the network without any special treatment.
1	The packet is to be sent to the network using a precedence (i.e., priority) and TOS.
2 . . . 255	Reserved.

Table 10 illustrates exemplary Flow type (Type A1, Table 7). However, more or fewer flow types can also be used.

TABLE 10

Flow type	Definition
1	IP 54
2	ATM
3 . . . 255	Reserved

Table 11 illustrates exemplary ATM Flow sub-type (Type A3, Table 7). However, more or fewer ATM flow sub-types can also be used.

TABLE 11

ATM Flow Sub-type	Definition
1	Universal Bit Rate ("UBR")
2	Constant Bit Rate ("CBR")
3	Adaptable Bit Rate ("ABR")
4	Variable Bit Rate ("VBR")

In one exemplary preferred embodiment of the present invention, the CM 16 adds MAC 44 level Service Identifiers ("SIDs") requests to a registration message sent to the CMTS 12 to request CoS or QoS. These SIDs provide device identification, QoS and CoS management. In particular, they are integral to bandwidth identification. A SID defines a particular mapping between the CM 16 and the CMTS 12. In one exemplary preferred embodiment of the present invention, this mapping is the basis on which bandwidth is allocated to the CM 16 by the CMTS 12 and which CoS and QoS are implemented. Within the MAC 44, SIDs are unique and the CMTS 12 may assign one or more SIDs to each CM 16, corresponding to the CoS or QoS required by a CM 16. Table 12 illustrates exemplary MAC 44 SID parameters in TLV format. However, more or fewer SID parameters can also be used. In addition SIDs may be used in other layers beside the data-link layer 42 for bandwidth identification (e.g., the network layer 52 or the transport layer 58, etc.).

TABLE 12

Type/Subtype	Length	Description of Value	Default Value
Bx	N	Service Identifier Header	
B0	1	Service Identifier Type	0
B1	1	Number of Service Identifier's (SIDs) to be given with this definition	1
B2	4	Flow Identifier for SIDs	0
B3	4	CoS for SIDs	0
B4	4	Source IP 54 address	CM's IP 54 address
B5	4	Source IP 54 address mask	255.255.255.255
B6	4	Destination IP 54 address	255.255.255.255
B7	4	Destination IP 54 address mask	255.255.255.255
B8	1	IP Protocol Type	256
B9	4	Source Port (Start)	0
B10	4	Source Port (End)	65,535
B11	4	Destination Port (Start)	0
B12	4	Destination Port (End)	65,535
B13	1	Precedence and TOS	0
B14	1	Precedence and TOS Mask	255
B15	N	Multicast group definition	Null string""
B16	4	Protocol Type	0xfffffff
B17-B127	N	Reserved	
B128-B255	N	Vendor Specific	

Table 13 illustrates exemplary multicast and unicast Service Identifier Type values (Type B0, Table 12). However, more or fewer service identifier types can also be used.

TABLE 13

Service Identifier Type Value	Value Definition
1	Outgoing unicast from CM 16
2	Outgoing multicast from CM 16
3	Incoming unicast to CM 16
8	Outgoing multicast to CM 16

Table 14 illustrates exemplary IP Protocol Type values (Type B8, Table 12). However, more or fewer IP protocol types can also be used.

TABLE 14

IP Protocol Type Value	Value Definition
1	ICMP 56
2	Transmission Control Protocol ("TCP")
4	UDP 60
256	Any Protocol

Table 15 illustrates exemplary Protocol Type values (Type B16, Table 12). However, more or fewer protocol types can also be used.

TABLE 15

Protocol Type Value	Value Definition
0	No Protocols Allowed
1	IP 54
2	Internet Packet exchange ("IPX")

TABLE 15-continued

Protocol Type Value	Value Definition
4	Appletalk
8	ATM
0xfffffff	All protocols allowed

Table 16 illustrates an exemplary parameter for a number of CPEs 18 that can connect to a CM 16 during a session. However, more or fewer number of CPEs can also be used.

TABLE 16

Type	Length	Description of Value	Default
H	2	Number of CPEs 18 that can connect to CM 16 during a session	1 = CPE 18 or 0xfffffff = any number of CPEs 18

Returning to FIG. 7 at Step 156, one or more pools of IP 54 addresses are specified for the one or more service level agreements. Table 17 illustrates exemplary pools of IP 54 addresses specified for the one or more service level agreements shown in Table 5. However, the present invention is not limited to this exemplary pool of IP 54 addresses.

TABLE 17

Plan	IP 54 Pool
Biz Gold	24.4.56.1-24.4.56.255
Biz Silver	24.4.32.1-24.4.32.127
Gold	24.4.36.1-24.4.36.127
Silver	24.4.53.1-24.4.53.127
Premium	24.4.26.1-24.4.26.127

At Step 158, the bandwidth manager 146 (FIG. 6) is notified of the one or more service level agreements and one or more pools of IP 54 addresses. In one exemplary preferred embodiment of the present invention, the bandwidth manager 146 will also preferably include a cable modem traffic management service level agreement and a bandwidth manager 146 pool of IP 54 addresses. The bandwidth manager 146 pool includes IP 54 addresses that can be assigned to the CMs 16 by the DHCP server 150 for maintenance or other purposes. This insures that the CM management traffic service level agreement, including things as software upgrades, maintenance messages, emergency messages, and other messages, gets the appropriate priority and is not starved by higher priority service level agreements in the bandwidth manager 146.

Table 17 illustrates an exemplary cable modem management service level agreement. However, other service level agreements can also be used and the present invention is not limited to the service level agreement in Table 18.

TABLE 18

Plan	CIR Down	MBR Down	CIR Up	MBR Up	Priority	Time
CM Mgmt	512K	1024K	256K	256K	1	ALL

Table 19 illustrates an exemplary cable modem management IP 54 address pool of the cable modem management service level agreement of Table 18. However, the present invention is not limited to this pool of IP addresses.

TABLE 19

Plan	IP 54 Pool
CM Mgmt	20.3.53.0, 20.3.54.0

At Step 160, the one or more pools of Internet Protocol addresses (e.g., Tables 17 and 19) are assigned to the DHCP 66 server 150. The DHCP 66 server 150 assigns IP 54 addresses from the one or more pools for network devices requesting desired service level agreements on the bandwidth provisioning data-over-cable system 140. In one exemplary preferred embodiment of the present invention, the one or more service level agreements are assigned an IP 54 address from IP 54 address pools associated with in the DHCP 66 server 150.

At Step 162, one or more configuration files for the one or more service level agreements are created. The one or more configuration files are used to initialize a CM 16 or CPE 18 network device with desired service level agreement parameters on the data-over-cable system 140. In one exemplary preferred embodiment of the present invention, the configuration files are created using the DOCSIS standard. Such DOCSIS configuration files also include CoS and Requesting a Service Level Agreement

In one exemplary preferred embodiment of the present invention, the data-over-cable 140 and Method 152 are used to provide bandwidth provisioning for CoS and QoS requests from CMs 16 and CPEs 18. FIG. 8 is a flow diagram illustrating a Method 166 for requesting service level agreements.

In FIG. 8 at Step 168, a network device requests a service level agreement with a desired class-of-service or quality-of-service from a cable modem termination system. At Step 170, the network device provides a data-link layer address on the data-over-cable system to the cable modem termination system to identify the network device. At Step 172, a network address is statically reserved for the network device on the data-over-cable system from the cable modem termination system. The statically reserved network address is from a pool of network addresses associated with the requested service level agreement. At Step 174, a network address is dynamically requested on the network device during a boot sequence. A network address server associated with the cable modem termination system allocates the reserved network address to the network device from the pool of network addresses associated with the requested service level agreement. At Step 176, the statically reserved network address is received on the network device in response to the dynamic request for a network address. At Step 178, a configuration file is received on the network device in response to the boot sequence. The configuration file is used to initialize a network device with configuration parameters and a desired service level agreement on the data-over-cable system. The configuration file includes default initialization parameters as well as service level agreement parameters. At Step 180, the configuration file is used to initialize the network device. Loading the configuration file on a network device QoS parameters in DOCSIS TLV format (e.g., examples illustrated in Tables 6-15). The configuration files also include default configuration parameters used to initialize a CM 16 or CPE 18 whether or not service level agreements are not used.

In one exemplary preferred embodiment of the present invention, the configuration files specify at least a Maximum Rate Limit ("MRL") for both a downstream and an upstream connection based on a respective CoS policy for a service

level agreement. In one preferred embodiment of the present invention, the CMTS 12 to CM 16 or CPE 18, CoS capability is limited to enforcement of maximum bit rates. Since upstream CoS policy enforcement also depends on this downstream rate limitation interaction, the same bandwidth rate is used for upstream CIR and MBR. However, in another preferred embodiment of the present invention, the CoS policy enforcement is not limited only to enforcement of MBR and a separate list of upstream and downstream limits can also be enforced. Table 20 illustrates a list of exemplary configuration files created at Step 160.

TABLE 20

Plan	Config File Name	MRL Down	MRL Up
Biz Gold	BizGold.conf	1544K	512K
Biz Silver	BizSilver.conf	800K	256K
Gold	Gold.conf	512K	128K
Silver	Silver.conf	256K	64K
Premium	Premium.conf	128K	40K

At Step 164, the MRL and other CoS or QoS bandwidth information from the configuration files is loaded in the cable access router 144. The cable access router 144 uses the CoS or QoS information to enforce the MRLs for a desired service level agreement between the CMTS 12 and CMs 16 or CPEs 18. includes setting one or more parameters for class-of-service or quality-of-service for the desired service level agreement.

In one exemplary preferred embodiment of the present invention, Method 166 is used on exemplary data-over-cable system 140 to request service level agreements. However, the present invention is not limited to this implementation, and other data-over-cable systems can also be used. In such an embodiment, at Step 168 a CM 16 and/or CPE 18 requests a service level agreement with a desired class-of-service or quality-of-service from CMTS 12. At Step 170, the CM 16 and/or CPE 18 provides a MAC 44 address to the CMTS 12 to identify the network device.

In one exemplary preferred embodiment of the present invention, the MAC 44 address is sent to the CM 16 or CPE 18 in a TSI message 76 (FIG. 4). However, other methods may also be used to dynamically or statically assign a MAC 44 address.

At Step 172, an IP 54 address is statically reserved for the CM 16 and/or the CPE 18 using a static DHCP 66 reservation. As is known in the art, a device can statically reserve an IP 54 address using DHCP 66, but can still receive the IP 54 address dynamically from a DHCP 66 server.

At Step 174, the statically reserved IP 54 address is dynamically requested on the CM 16 and/or CPE 18 during a boot sequence. A CM 16 is recognized by an addressing scope different from the CPE 18 using DHCP 66. A DHCP giaddr-field 130 (FIG. 5) is set with an IP 54 address for a CM 16 when a CPE 18 is requesting a statically reserved IP 54 address from a pool associated with a desired service level agreement. The DHCP giaddr-field 130 may also be set with an IP 54 address for a downstream cable channel from the CMTS 12 when a CM 16 is requesting a statically reserved IP 54 address. In one preferred embodiment of the present invention a "Request IP Address" option 50 in the DHCP 66 message options-field 138 (FIG. 5) is set to include the statically reserved IP 54 address. This DHCP option 50 allows a request for a specific IP 54 address (i.e., a statically reserved IP 54 address). Thus, CM 16 and/or CPE 18 will send a DCHPDISCOVER message as described above in Table 4b with the DHCP 66 options-field 138 including DHCP option 50. This option field includes the



statically reserved IP 54 address from the pool of network addresses associated with the requested service level agreement. However, other options and other methods may also be used to request the statically reserved IP 54 address. The DHCP 66 server 150 associated with CMTS 12 dynamically allocates the statically reserved IP 54 address to the CM 16 and/or the CPE 18 from the pool of IP 54 addresses associated with the requested service level agreement.

At Step 176, the statically reserved IP 54 address is dynamically received on the CM 16 and/or the CPE 18 via DHCP 66 server 150 in response to the request for a dynamically assigned IP 54 address (i.e., a request with a DHCPDISCOVER message). In one exemplary preferred embodiment of the present invention, the statically reserved IP 54 address is received on the CM 16 and/or the CPE 18 in a DHCPOFFER message in a yiaddr-field 126 from the DHCP 66 server 150 including the pool of IP 54 addresses associated with the requested service level agreement (e.g., see Table 4b). The CM 16 and/or the CPE 18 responds with a DCHPREQUEST message including the statically reserved IP 54 address in the DHCP yiaddr-field 126.

Step 178, a configuration file (e.g., from Table 19) is received on the network device in response to the boot sequence. The name for the configuration file is returned in a DHCPACK message file-field 136 from the DHCP 66 server 150 to the CM 16 and/or CPE 18. The configuration file is used to initialize a network device with a desired service level agreement on the data-over-cable system.

At Step 180, the configuration file is used to initialize the CM 16 and/or the CPE 18. Loading the configuration file includes setting one or more of the parameters for class-of-service or quality-of-service for the desired service level agreement. The desired service level agreement is enforced from the bandwidth manager 148 associated with the CMTS 12.

#### Enforcing Bandwidth Provisioning for Service Level Agreements

FIG. 9 is a flow diagram illustrating a Method 182 for enforcing bandwidth provisioning for service level agreements. At Step 184, a data stream is received on a cable modem termination system on a data-over-cable system for a first network device on the data-over-cable system from an external network. At Step 186, a test is conducted to determine from the cable modem termination system whether the data stream is to be controlled by a service level agreement. If the data stream is to be controlled by a service level agreement, at Step 188 the data transmission of the data stream is regulated using one or more parameters from the service level agreement. The data stream is regulated as data is sent from the cable modem termination to the first network device and as data is sent from the first network device back to the cable modem termination system. The cable modem termination system enforces class-of-service or quality-of-service from the service level agreement on the data stream between external network and the data-over-cable system. If the data stream is not to be controlled by a service level agreement, at Step 190 the data stream is not regulated by the cable modem termination system using a service level agreement.

In one exemplary preferred embodiment of the present invention, Method 180 is used on the exemplary data-over-cable system 140. However, the present invention is not limited to this implementation, and other data-over-cable systems can also be used. In such an embodiment at Step 184, a data stream is received on CMTS 12 on the data-over-cable system for the CM 16 or the CPE 18 on the data-over-cable system from an external network such as

PSTN 22 data network 28, or another cable network. The data stream may include voice, video or data information. At Step 186, a test is conducted from the CMTS 12 to determine whether the data stream is to be controlled by a service level agreement.

If the data stream is to be controlled by a service level agreement, at Step 188 the data transmission of the data stream is regulated using one or more parameters from the service level agreement. The data stream is regulated as data is sent from the CMTS 12 to the CM 16 or CPE 18 and as data is sent from the CM 16 or CPE 18 to the CMTS 12. If the data stream is not to be controlled by a service level agreement at Step 186, the data stream is not regulated with service level agreement by the CMTS 12 at Step 190.

Regulating data transmission of the data stream includes detecting data transmission trends, measuring data transmission response times and generating class-of-service or quality-of-service reports. In one exemplary preferred embodiment of the present invention, the desired service level agreement is enforced from the bandwidth manager 148 associated with the CMTS 12. The cable access router 144 associated with CMTS 12 also enforces MRLs for a desired service level agreement.

#### Adjusting Data Transmission for Service Level Agreements

In one preferred embodiment of the present invention the bandwidth manager 148 may also monitor, and regulate data transmission based on service level agreement requests. FIG. 10 is a flow diagram illustrating a Method 192 for monitoring and regulating data transmission using service level agreements.

In FIG. 10 at Step 194, a first data transmission rate is monitored from a data-link layer on a cable modem termination system on a connection to a first network device using a first service level agreement. In one exemplary preferred embodiment of the present invention, the cable modem termination system monitors the first data transmission rate from the data-link 42 layer using one or more class-of-service or quality-of-service parameters from the first service level agreement. In another embodiment of the present invention, the cable modem termination system monitors the first data transmission in a layer above the data-link layer 42 (e.g., the network layer 52, the transport layer 58, etc.). At Step 196, the first data transmission rate on the connection is regulated from the data-link layer on the cable modem termination system using messages from a data-link layer protocol.

The first data transmission rate can also be adjusted from the cable modem termination system. A request from the first network device is received on the data-link layer on the cable modem termination system to use a second service level agreement on the connection from the cable modem termination system to the first network device. The first data transmission rate is adjusted to a second data transmission rate on the cable connection from the data-link layer on the cable modem termination system. The second data transmission rate includes a first data stream part regulated from the data-link layer using the first service level agreement and a second data stream part regulated from the data-link layer using the second service level agreement.

In one exemplary preferred embodiment of the present invention, Method 192 is used on the exemplary data-over-cable system 140. However, the present invention is not limited to this implementation, and other data-over-cable systems can also be used. In such an embodiment at Step 194, a first data transmission rate is monitored from a data-link layer 42 on the bandwidth manager 146 associated with the CMTS 12 on cable connection to the CM 16 or CPE

18 using a first service level agreement. In one exemplary preferred embodiment of the present invention, the bandwidth manager 146 monitors the first data transmission rate from the data-link 42 layer using one or more class-of-service or quality-of-service parameters from the first service level agreement. In another embodiment of the present invention, the bandwidth manager 146 monitors the first data transmission in a layer above the data-link layer 42 (e.g., the network layer 52, the transport layer 58, etc.). In one exemplary preferred embodiment of the present invention at Step 196, the first data transmission rate on the cable connection is regulated from the data-link layer 42 by the bandwidth manager 146 using MAC 44 messages. In another exemplary preferred embodiment of the present invention, the bandwidth manager 146 uses messages from other protocols above the data-link layer 42 to regulate data transmission.

#### Shaping Data Traffic Using Service Level Agreements

In one preferred embodiment of the present invention, the bandwidth manager 146 associated with the CMTS 12 may also shape data traffic based on service level agreement requests. In one exemplary preferred embodiment of the present invention, the traffic shaping is conducted from the data-link layer 42. In another preferred embodiment of the present invention, the traffic shaping is conducted from a layer above the data-link layer 42.

FIG. 11 is a flow diagram illustrating a Method 200 for shaping data traffic using service level agreements. At Step 202, a first data transmission rate on a connection from a cable modem termination system to a first network device is regulated using a first service level agreement. The cable modem termination system regulates the first data transmission rate one or more class-of-service or quality-of-service parameters from the first service level agreement. At Step 204, a request is received from the first network device on the cable modem termination system to use a second service level agreement along with the first service level agreement on the connection from the cable modem termination system to the first network device. Use of the first service level agreement and the second service level agreement on the connection requires a second data transmission rate on the connection that will exceed a maximum data transmission rate available for the connection.

At Step 206, the first data transmission rate on the connection is adjusted dynamically to a third data transmission rate. The third data transmission rate includes a first data stream part regulated using a third service level agreement and a second data stream part regulated using the second service level agreement. The third service level agreement includes one or more class-of-service or quality-of-service parameters different from the first service level agreement. Regulating the third data transmission rate on the connection using the second service level agreement and the third service level agreement does not exceed the maximum data transmission rate available for the connection. The third service level agreement includes one or more class-of-service or quality-of-service parameters for a lesser service level for a lower data transmission rate than included the first service level agreement.

In one exemplary preferred embodiment of the present invention, Method 200 is used on the exemplary data-over-cable system 140. However, the present invention is not limited to this implementation, and other data-over-cable systems can also be used. In such an embodiment at Step 202, a first data transmission rate on a cable connection from the CMTS 12 to the CM 16 or the CPE 18 is regulated by the bandwidth manager 146 associated with the CMTS 12

using a first service level agreement (e.g., Biz Gold, Table 5). The bandwidth manager 146 regulates the first data transmission rate one or more class-of-service or quality-of-service parameters from the first service level agreement.

At Step 204, a request is received from the CM 16 or the CPE 18 on the bandwidth manager 146 associated with CMTS 12 to use a second service level agreement (e.g., 2<sup>nd</sup> Biz Gold, Table 5) along with the first service level agreement (1<sup>st</sup> Biz Gold, Table 5) on the cable connection to the CM 16 or the CPE 18. Use of the first service level agreement and the second service level agreement on the connection requires a second data transmission rate on the cable connection that will exceed a maximum data transmission rate available for the cable connection.

In one embodiment of the present invention, the second service level agreement is the same as the first service level agreement (e.g., Two Biz Gold from Table 5). In another embodiment of the present invention, the second service level agreement is not the same as the first service level agreement (e.g., a Biz Gold and a Biz Silver, respectively from Table 5).

At Step 206, the first data transmission rate on the connection is adjusted dynamically by the bandwidth manager 146 to a third data transmission rate. The third data transmission rate includes a first data stream part regulated using a third service level agreement (e.g., Silver, Table 5) and a second data stream part regulated using the second service level agreement (e.g., 2<sup>nd</sup> Biz Gold, Table 5). The third service level agreement includes one or more class-of-service or quality-of-service parameters different from the first service level agreement. Regulating the third data transmission rate on the connection using the second service level agreement and the third service level agreement does not exceed the maximum data transmission rate available for the connection. The third service level agreement includes one or more class-of-service or quality-of-service parameters for a lesser service level (e.g., Priority 4 instead of highest Priority 1) for a lower data transmission rate than included the first service level agreement (e.g., 256K MBR for Silver down instead of 1544K MBR down for 1<sup>st</sup> Biz Gold).

In one exemplary preferred embodiment of the present invention, the third service level agreement may be dynamically adjusted to a "best-effort" service level agreement. Such a best-effort service level would be a lowest priority service level (e.g., priority 6) and would not guarantee any data at all. The bandwidth manager 146 would make a best effort to transmit data only after all the higher priority service level agreement data is transmitted.

The methods and system described herein may allow service level agreements to be used on a data-over-cable system without adversely affecting performance or throughput on the data-over-cable system. The methods and system of the present invention may also help provide service level agreements on a data-over-cable system in a more reliable manner.

It should be understood that the programs, processes, methods, systems and apparatus described herein are not related or limited to any particular type of computer apparatus (hardware or software), unless indicated otherwise. Various types of general purpose or specialized computer apparatus may be used with or perform operations in accordance with the teachings described herein. While various elements of the preferred embodiments have been described as being implemented in software, in other embodiments hardware or firmware implementations may alternatively be used and visa-versa.

29

In view of the wide variety of embodiments to which the principles of the invention can be applied, it should be understood that the illustrative embodiments are exemplary only, and should not be taken as limiting the scope of the present invention. For example, the steps of the flow diagrams may be taken in sequences other than those described, and more or fewer elements or component may be used in the block diagrams.

The claims should not be read as limited to the described order or elements unless stated to that effect. Therefore, all embodiments that come within the scope and spirit of the following claims and equivalents thereto are claimed as the invention.

We claim:

1. In a data-over-cable system with a plurality of network devices, a method for requesting a service level agreement, the method comprising the steps of:

requesting on a network device, a service level agreement with a desired class-of-service or quality-of-service from a cable modem termination system;

providing a data-link layer address for the network device on the data-over-cable system to the cable modem termination system to identify the network device;

reserving statically a network address for the network device on the data-over-cable system from the cable modem termination system, wherein the statically reserved network address is reserved from a pool of network addresses associated with the requested service level agreement;

requesting dynamically a network address on the network device during a boot sequence, wherein a network address server associated with the cable modem termination system allocates the statically reserved network address to the network device from the pool of network addresses associated with the requested service level agreement;

receiving dynamically the statically reserved network address on the network device agreement in response to the dynamic request for a network address;

30

receiving a configuration file on the network device in response to the boot sequence, wherein the configuration file is used to initialize a network device with a desired service level agreement on the data-over-cable system; and

initializing the network device with the configuration file, wherein loading the configuration file includes setting a plurality of parameters for class-of-service or quality-of-service for the desired service level agreement on the network device.

2. A computer readable medium having stored therein instructions for causing a central processing unit to execute the method of claim 1.

3. The method of claim 1 wherein the data-link layer address is a Medium Access Control protocol address and the network address is an Internet Protocol address.

4. The method of claim 1 wherein the network address server is a Dynamic Host Configuration Protocol server.

5. The method of claim 1 wherein step of loading the configuration file on the network device includes setting maximum transmission and reception rate limits from the configuration file on the network device to comply with a desired class-of-service or quality-of-service for the desired service level agreement.

6. The method of claim 1 further comprising:

operating the network device using the plurality of class-of-service or plurality-of-service parameters from the desired service level agreements; and

enforcing the desired service level agreement from a bandwidth manager associated with the cable modem termination system on a connection between the cable modem termination system on a cable modem by regulating data transmission flow on the connection according to the service level agreement.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 6,553,568 B1  
DATED : April 22, 2003  
INVENTOR(S) : John G. Fijolek et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,

Item [75], Inventors, please delete "**Phillip T. Robinson**" and substitute  
-- **Philip T. Robinson** --; and please delete "**Narij Jain**" and substitute -- **Niraj Jain** --

Signed and Sealed this

Eighteenth Day of November, 2003

A handwritten signature in black ink, appearing to read 'James E. Rogan', with a horizontal line drawn underneath it.

JAMES E. ROGAN  
*Director of the United States Patent and Trademark Office*